Chapter 1

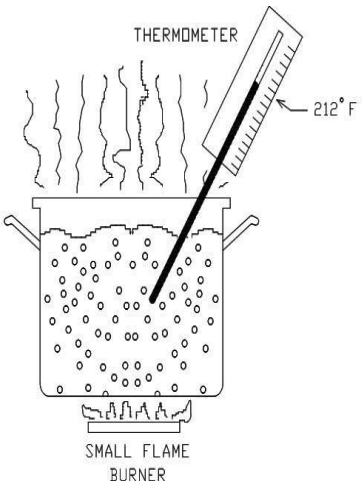
FUNDAMENTALS OF STEAM

A boiler is defined as an enclosed pressure vessel in which water is heated. The fire in or under the boiler turns the chemical energy in the fuel into heat energy. If the boiler is designed so that the water does not turn the heat energy into steam, then the boiler is called a hot water or hydronic boiler. If the boiler does turn the heat energy into steam then it is called a steam boiler. If a boiler is designed to produce steam at a pressure over 15 pounds per square inch it is considered to be a high pressure boiler. If a boiler is designed to produce steam at a pressure of 15 pounds per square inch or less it is considered to be a low pressure boiler. For the purposes of this book we will concern ourselves only with steam boilers.

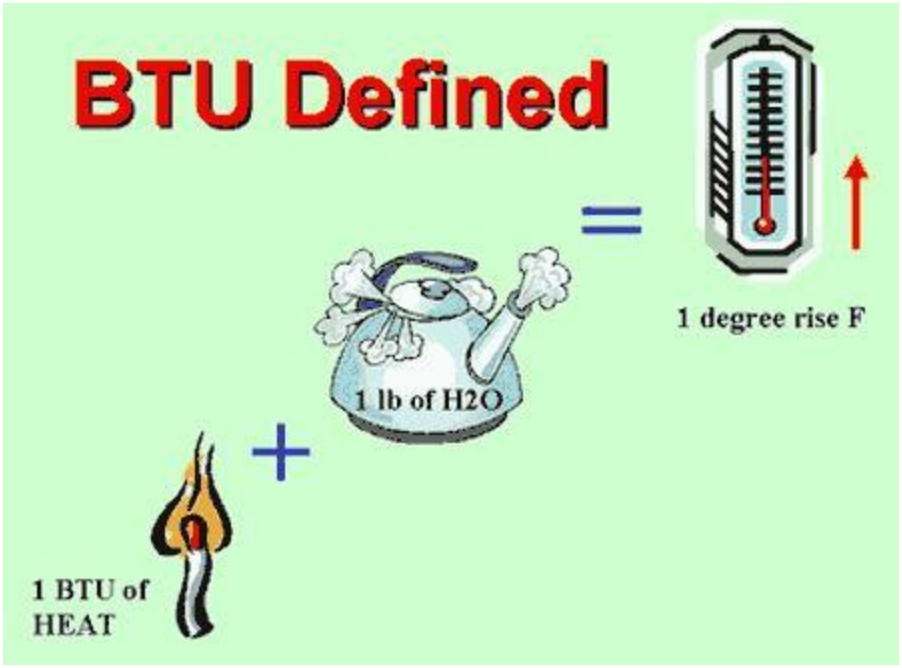
In this chapter we will discuss the physical properties of steam. We will describe how those properties of steam change under pressure and how we can use steam to provide heat and power for practical purposes.

Let's take a pot of water boiling on a stove and put in a thermometer. If we are at sea level the thermometer will read 212 degrees Fahrenheit. The temperature of the gas flame could be 2000 degrees Fahrenheit and yet the water does not get hotter than 212 degrees Fahrenheit. Why is this?

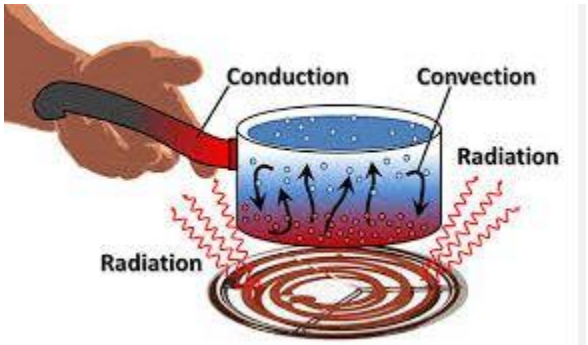
The water is releasing heat it is absorbing from the fire into the air in the form of steam. Steam is invisible so what is seen is the condensate that the hot steam is forming as it is coming in contact with the cooler air surrounding the steam. If water is boiled in a tea pot, a space is seen between the outlet of the tea pot and the condensate. That is steam.



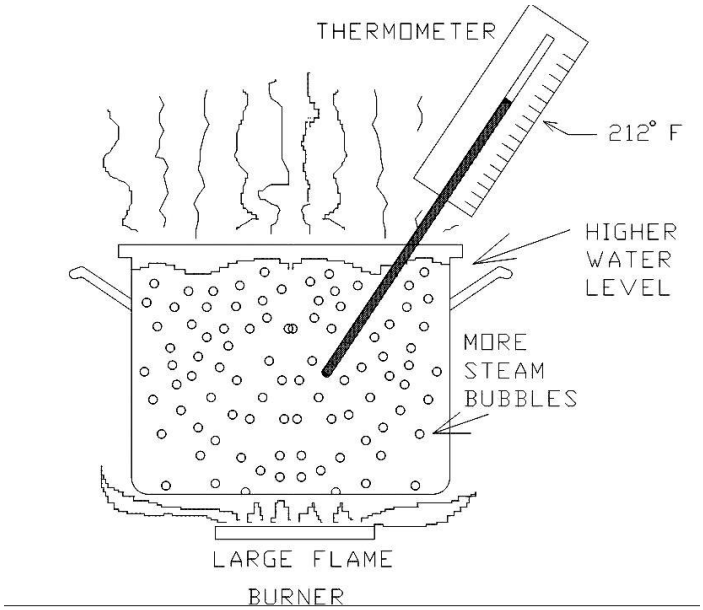
The steam boils at 212 degrees Fahrenheit only at sea level. If we were to go up in the mountains the water would boil at a lower temperature because the pressure of the atmosphere on our pot of water would be less. People complain that the air is "thin" at higher elevations due to this decrease in air pressure. Death Valley in California is 282 feet below sea level at its lowest point. Water will boil at a temperature above 212 degrees Fahrenheit in Death Valley due to the increase in atmospheric pressure.



A BTU (British Thermal Unit) is the amount of heat needed to raise one pound of water one degree Fahrenheit. One small kitchen match burning down to ash will provide approximately one BTU. So heat has the weight of the water to be considered as well as the temperature. Temperature is defined as the intensity of the heat. The weight of the water or other substance is not considered when discussing temperature.

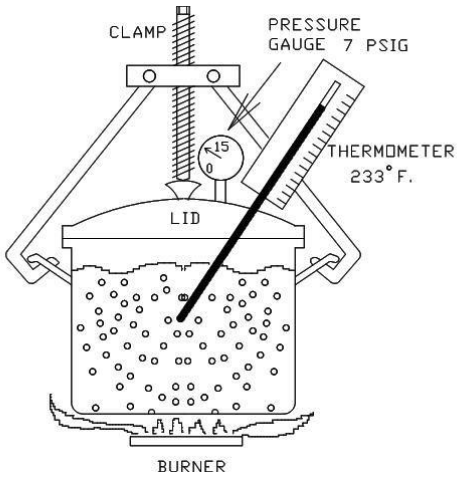


Heat travels in three ways, through conduction, convection, and radiation. The flame of the stove is actually touching the bottom of the pot and is directly conducting the heat from the flame to the pot. The pot is also conducting the heat through the metal of the pot to the water at the very bottom of the pot. The water inside the pot is being heated by the convection currents being set up as the hot water rises up through the cooler water and heats it from molecule to molecule as it passes. The outside of the pot is also being heated by convection by the hot combustion gasses travelling around the outside of the pot. Radiant heat must be "seen" by the object in order to receive the heat. The parts of the pot that are not in direct contact with the flame but are within "sight" of the flame are receiving radiant heat. You may be familiar with the radiant heat panels used near the outside entrance to stores. You do not feel warm air blowing on you (convection), and you are not touching anything (conduction), but you can feel the heat on your face by the heater in the ceiling (radiation).



Now let's go back to our pot of water. It is a property of water that as it is heated from water at 212 degrees Fahrenheit to its boiling point at 212 degrees Fahrenheit, the water will absorb 970 BTU's per pound. Where is the 970 BTU's going that is being absorbed into the water? The transformation of water into steam takes that 970 BTU's and is referred to as latent heat of vaporization. A proper definition is that it is the heat required to bring about a change in a substance from liquid to a vapor with no increase in temperature. If we increase the size of the gas flame under our pot of boiling water we can increase the rate at which the water boils and make it boil faster, but the temperature of the water will stay at 212 degrees Fahrenheit. Each pound of steam that is released from our pot of water will contain 970 BTU's. The reverse is also true. If steam at 212 degrees Fahrenheit is allowed to cool back to water it will release 970 BTU's. These BTU's can be used to heat buildings or drive heat engines such as steam engines or steam turbines.

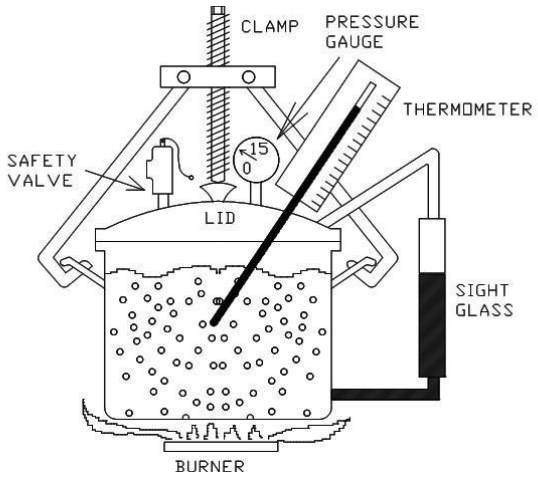
If we really think about our pot of water we can see that the water is keeping the pot from burning. If we did not have water in the pot, the steel would melt and ruin the pot. This is why it is essential to keep the water level in the boiler in the sight glass or else the steel from which the boiler is made will melt the tubes and ruin the boiler or collapse the metal and cause a steam explosion.



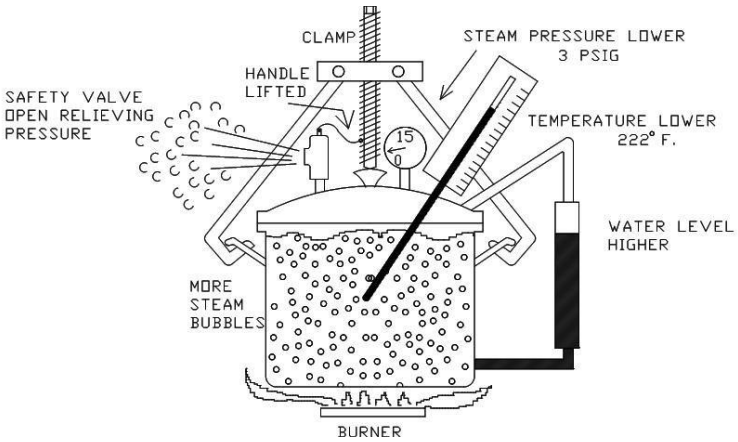
Now, let's clamp a lid on the pot and put a pressure gage on the lid. Now our pot of water is similar to a pressure cooker. Notice that as the pressure increases, the temperature increases. We have discovered that the temperature the water boils at depends upon the pressure that is forced upon the water. Why did the pressure increase when we clamped the lid on? When water turns to steam it expands to 1600 times the volume it occupied before it turned to steam.

This increase in volume can keep creating an increase in the steam pressure until our pot can no longer contain the pressure and the pot rips open with a violent explosion as the pressure is suddenly released. All the water in the pot is instantly turned to steam. Remember at atmospheric pressure water boils at 212 degrees F. But our water is above 212 degrees F because of the pressure on the pot.

If the pot tears open, all water in the pot instantly flashes to steam, expanding 1600 times and blowing the pot to smithereens. This is why boiler explosions are so dangerous. You have a large amount of water turning to steam instantly with enough force to level the boiler room. Parts of the boiler have been found 1/4 mile away from the site of a steam explosion.



So how do we prevent our pot from exploding? Let's put a spring loaded safety valve on top of the pot and when the pressure gets too high the safety valve will pop open and relieve the excess pressure. Let's also add a sight glass to the pot so we can see the water level inside.



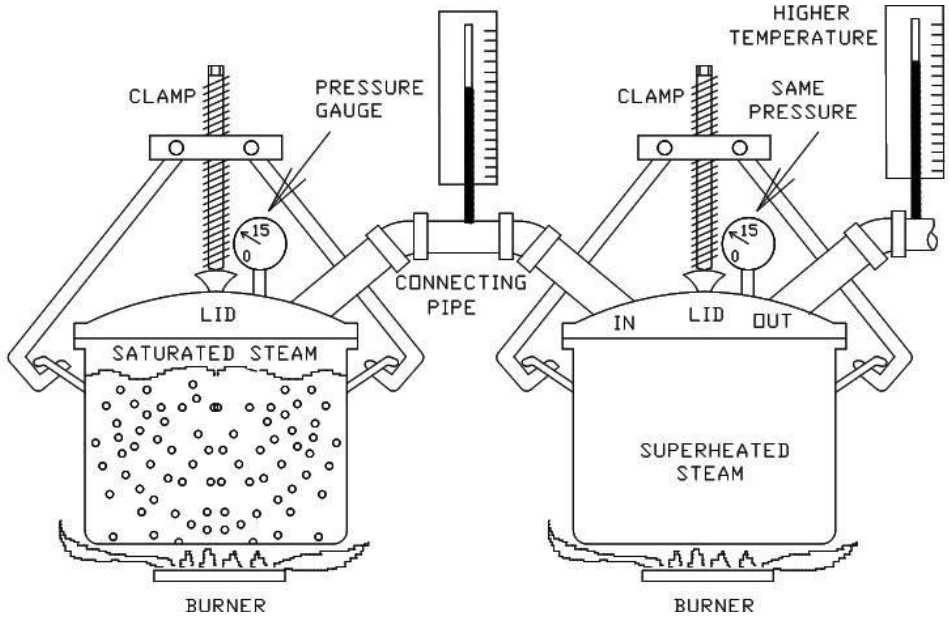
Now let's lift the handle on the safety valve to let out some steam and see what happens. As we lift the lever and let out some steam the water level rises in the pot. Why does the level rise when we are letting out steam? Shouldn't the water level drop since there is now less water in the pot?

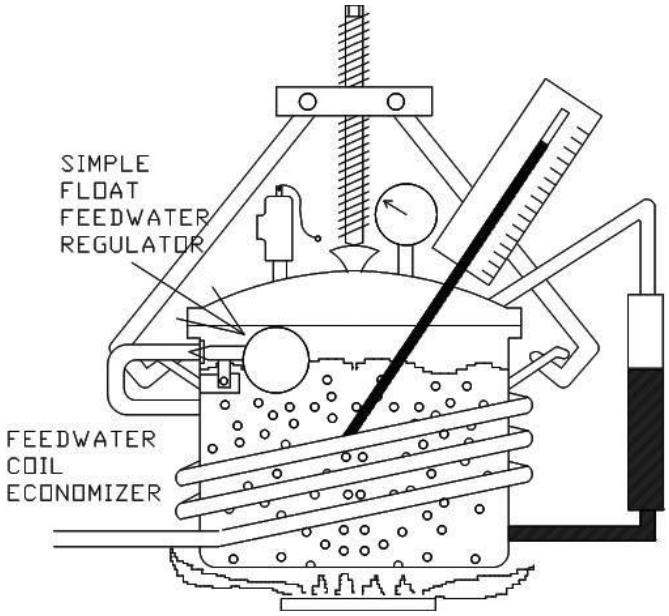
Remember that for every pressure there is a corresponding temperature. When we lifted the lever we lowered the pressure and therefore the temperature of the water and the steam. This caused the water to boil throughout the water and since steam bubbles are bigger than the water they came from they have the effect of raising the water level in the pot. Notice that this effect is only temporary because as soon as we drop the lever on the safety valve, the water level drops to a lower level than before. This is why when a sudden demand for steam is thrown on the boiler the water level rises. Sometimes the water level rises high enough to blow the high water whistle. The Operator in seeing the high water level in the sight glass might react hastily and start draining down the boiler to lower the water level. This is the last thing that the Operator should be doing because the water level will drop on its own when the boiler settles out at its new pressure. The burner will pick up the firing rate because of the lower steam pressure and the boiler will have a low water condition very shortly. Low water in the boiler can cause the boiler to overheat and destroy the boiler. There are steam demand meters that will tell an Operator if a sudden steam demand has been put on the boiler. The rise in the boiler water level due to an increase in steam demand is a very common phenomenon in the boiler room and yet very few Boiler Operators can explain the correct reasons for it.

Gage Press.	Temp. F.
0	212
1	216
2	219
3	222
4	224
5	227
6	230
7	232
8	235
9	237
10	240
15	250
20	259
25	267
30	274
35	281
40	287
45	292
50	298
55	303

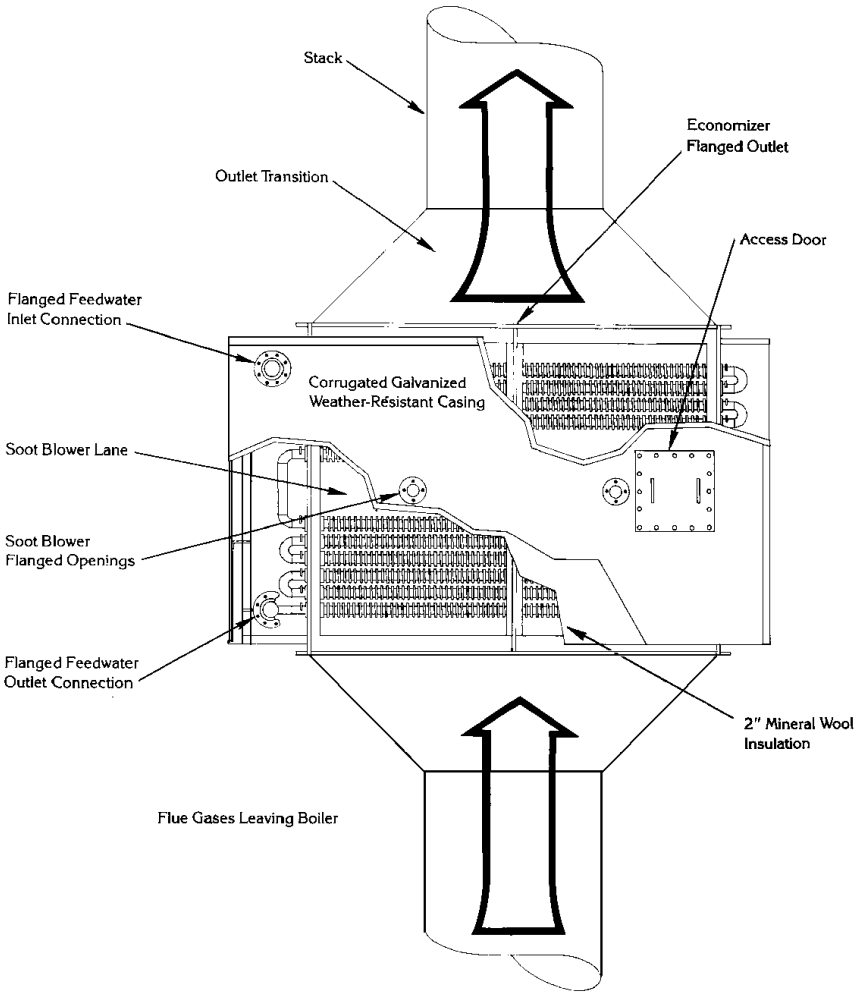
If we were to track the temperature at each point as the pressure increased one pound per square inch, we would be able to make a table known as a steam table. Fortunately this work has already been done for us and all we have to do today is refer to the steam table to find the temperature of steam at a particular pressure. Note that there is no mathematical formula to determine the steam temperature at a particular pressure. Someone had to physically measure each degree of temperature increase for each pound per square inch of pressure increase. This table is important to Boiler Operators who need to know the temperature of the steam at the different pressures the boiler generates steam.

So far in our discussion we have described the action of steam in contact with the water it is being generated from. Steam at the temperature corresponding to the pressure it is generated at is called saturated steam. Steam can be completely dry or wet with droplets and still be saturated steam if the temperature corresponds to the pressure that we described in our steam tables. What if we ran a pipe from the top of our pot to another enclosed pot that did not have any water in it and set the other pot on the burner next the first pot? Now we can run the steam from our first pot through the second pot. If we turn on the second burner, we will heat the steam to a temperature higher than that corresponding to its pressure. The steam coming out the outlet of the second pot will be superheated. Superheating means to heat steam to a higher temperature than the saturated steam temperature that corresponds to the pressure in the steam tables. Superheating is useful in heat engines such as turbines to get more power from a pound of steam because there is more heat in superheated steam than in saturated steam. All conventional electrical generating plants superheat the steam going to the turbines so that the maximum electrical output can be generated from the fuel. The type of superheater that we have built on the stove is called a separately fired superheater because we have the separate flame from the second burner heating the steam. Normally, we will use the hot combustion gasses from the completely burned fuel of the first burner to superheat the steam.



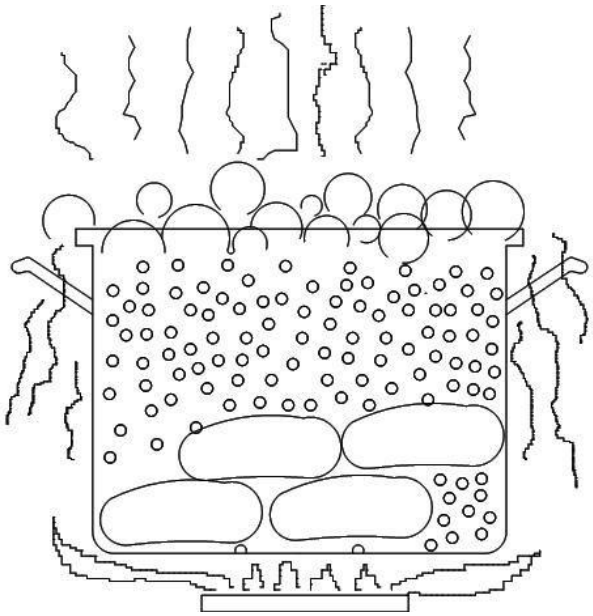


We can also use the hot combustion gasses of the completely burned fuel to heat the incoming feedwater by making a coil around our first pot. If we can use the hot combustion gasses to preheat our feedwater, we do not have to burn as much fuel to create steam. This will save money. Since it saves money we will call the coil of tubing an economizer because we are economizing on our fuel budget. In medium and larger sized boiler rooms, economizers are used for exactly that purpose.

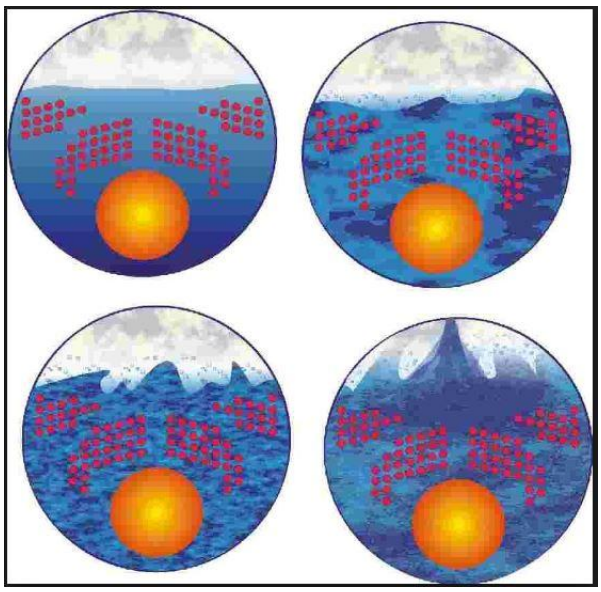


Courtesy Holman Boilers

Now let's relieve all the pressure, take the top off of our pot, add some potatoes, and turn the burner on high. Before too long the water starts forming large bubbles and starts boiling over the sides of the pot. What has happened?

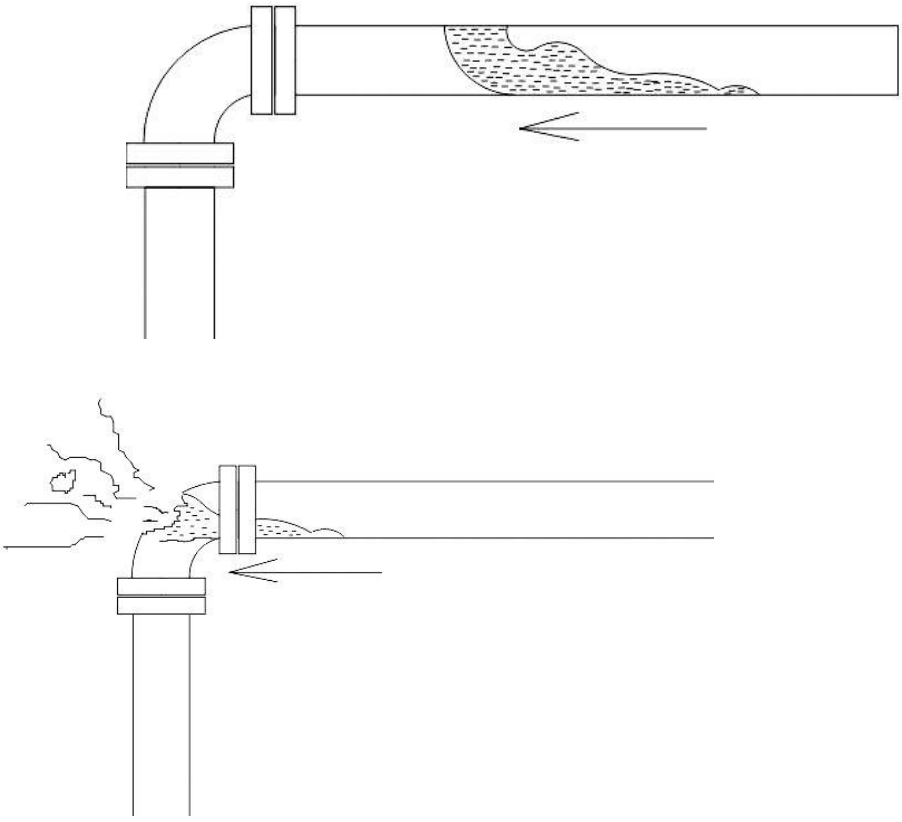


The cooking potatoes started forming a film on top of the water. As the steam bubbles rose to the surface, they could not easily break through the film and so more and more steam bubbles built up until the boiling water overflowed the pot. In the same way impurities in boiler water can create a film that causes the exact same thing to happen. This is called "foaming" when the bubbles build up on top of the water. If the bubbles rise high enough to carry water out the steam pipe then "priming" occurs. "Priming" also occurs when the water level rises high enough to be carried out when the steam pressure suddenly drops as described in an earlier paragraph. If the boiler is fired at a higher intensity than it was designed for and the surface of the steam liberating space is not large enough, the violent splashing of the water in the boiler can reach the steam outlet.

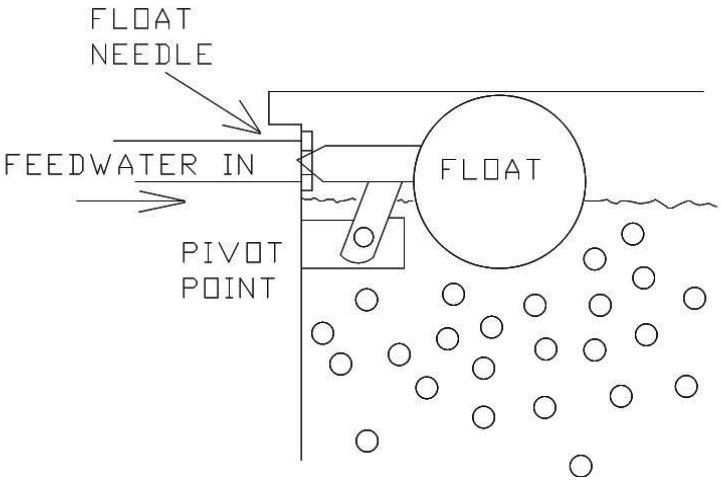


Increasing the firing rate increases the turbulence of the water

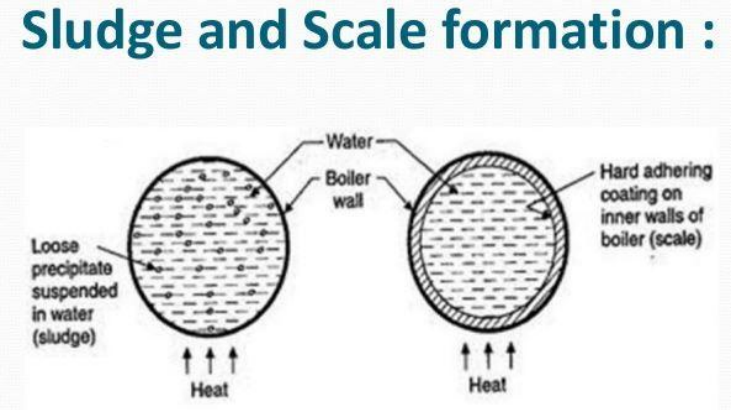
If the water gets into the steam pipe it is called carryover. If the water travels down the pipe until it hits a change in direction, the resulting banging is called "water hammer". Water hammer can lead to breaks in the steam piping and should be avoided at all costs. Water carried over to the steam engine is known as "slugging" and can cause the head of the engine to be knocked off. Water carried over into the turbine can cause the blades to be sheared off from their roots, so you can see how important it is to maintain the correct water level in the boiler and keep the boiler water clean.



Let's go back to our pot. As we boil water out of the pot it must be replaced. It becomes too tedious to keep adding water to the pot as it boils away so we add a float to keep the water level constant. Now as the water boils away the water is automatically fed to the pot. This is a type of feedwater regulator that we will be studying later.



As we continue to fill the pot and boil the water away, we notice a white buildup inside the pot. What is this? The water looked clear when we added it to the pot.



clean tube and scaled tube

The answer is that water is an excellent solvent. Since water is a solvent, the water will dissolve certain rocks and minerals that it comes in contact with in the earth. The carbonates and sulfates of calcium and magnesium create most of the scale problems in boilers. These dissolved solids will settle out or "plate" the inside of our pot as the water boils away, leaving a deposit known as scale. The water can turn to steam and leave the pot but the minerals remain behind. This is why we must treat our boiler water to get these minerals to group together in the water where they can be blown out drains at the surface of the water level and at the bottom of the boiler before they have a chance to plate out on the inside of our boiler. This scale can harm the boiler metal because the scale that the mineral deposits leave behind insulate the steel from the cooling effect of the water and cause the boiler steel to overheat and melt.

In our brief discussion of water boiling in a pot on the stove we have discovered the principles behind:

1. Steam Pressure-Temperature Relationship
2. Steam as an invisible vapor
3. Latent head of vaporization
4. Low water
5. High water
6. Necessity of safety valves
7. The relationship between water level and steam flow
8. Foaming
9. Priming
10. Carry-over
11. Water hammer
12. Slugging
13. Feedwater regulators
14. Scale

In conclusion, there is nothing more mysterious going on in the boiler than what is going on in a pot of boiling water or pressure cooker sitting on a stove. As long as you understand these simple principles, the steam and water cycle is easy to understand.

Chapter 1 Questions

1. Does water boil at the same temperature everywhere on Earth? Explain.
2. What do the initials BTU stand for? Define a BTU.
3. What is the difference between heat and temperature?
4. What are the three types of heat transfer? Which type of heat transfer does not have to touch you in order to be felt?
5. How many BTU's does it take to turn water into steam at 212 degrees Fahrenheit?
6. What keeps the fire from melting the metal of the pot?
7. What do you call the list of all steam pressures and their corresponding temperatures? Why is this list important to Boiler Operators?
8. When water turns to steam, how many times its original size does it expand?
9. Why does the water level in the boiler rise when there is a sudden demand for steam?
10. What is saturated steam?
11. What is superheated steam?
12. Why do we superheat steam?
13. What is an economizer and why is it used?
14. What causes foaming?
15. What two factors can cause priming?
16. What is carryover?
17. What is water hammer?
18. Define slugging?
19. Where does scale come from?
20. What are the constituents of scale?
21. Why is scale harmful?

Chapter 2

HISTORY OF STEAM BOILER DESIGN

In this chapter we will discuss how the design of steam boilers evolved. The function of the steam boiler is to convert and transfer of the chemical energy in the burning fuel into heat energy in the steam, and have it available for heating systems and for converting it into mechanical energy by steam engines and steam turbines. The fuel may be of fossil origin, such as coal, peat, or petroleum. It may also be of wood, straw, or bagasse (the fibrous refuse that remains after sugarcane or sorghum stalks are crushed to extract their juice.) The chemical energy of fuels found close to the Earth's crust was imparted to them by the sun. Some scientists propose that deeper deposits were formed within the Earth without a solar origin. In 2009, a huge oil and methane gas deposit was found 7 miles below the Gulf of Mexico.

The definition of a steam boiler is an enclosed vessel where heat is applied, and water is boiled and converted into steam, which is available for power or heating.
Three simple ways of classifying boilers are:
1. Plain cylindrical, fire tube, water tube, and combination of fire tube and water tube.
2. Horizontal and vertical.
3. Stationary, locomotive, and marine.

The requirements of the ideal steam boiler are listed below. It should be understood that the 13 requirements which follow are for an "ideal" boiler. In practice in may not be possible or feasible to satisfy all of them. In fact, the design of a practical boiler must be a compromise. All of these requirements should be fulfilled as far as is possible at a justifiable cost. When economic conditions merit buying a boiler of lower cost, the requirements of safety must be met. Buying a "Non-Code" boiler can never be justified."*It is perfectly legal for an importer/manufacturer to sell a non-code boiler to an end user in the United States. It is perfectly legal for an end user to own a non-code boiler. The potential problem surfaces when an end user attempts to install and operate a non-code boiler. He could be in violation of jurisdictional requirements and may be prevented from operating his equipment ". Daniel Clemens, Vice President, Pemberton Fabricators, Inc.*

Chinese pressure vessel fails a Hydrostatic Test

THE REQUIREMENTS FOR AN IDEAL BOILER ARE:

1. Proper workmanship and simple construction, using materials which experience has shown to be the best, thus avoiding the necessity of early repairs.

2. A mud drum to receive the impurities deposited from the water and placed at a distance from the action of the fire so that the impurities have a chance to settle out and be blown down from the boiler.

3. A steam and water capacity sufficient to prevent any material fluctuation in steam pressure or water level.

4. A water surface area, for the disengagement of the steam from the water, of sufficient size to prevent priming.

5. A constant and thorough circulation of water throughout the boiler, maintaining all parts at nearly the same temperature as possible.

6. A form of construction which will eliminate, as far as humanly possible, the liability of disastrous explosions.

7. A great excess of strength over any legitimate strain. The boiler should be constructed to be free from strains due to unequal expansion. Joints exposed to the direct action of the fire should be avoided.

8. A combustion chamber designed so that the combustion of gases started in the furnace may be completely burned before exhausting to the outside.

9. Enough heating surface, relative to the direction of flow of the gases of combustion that will ensure the greatest possible transfer of heat from the fire to the water in the boiler.

10. Easy access to all parts for cleaning and repairs.

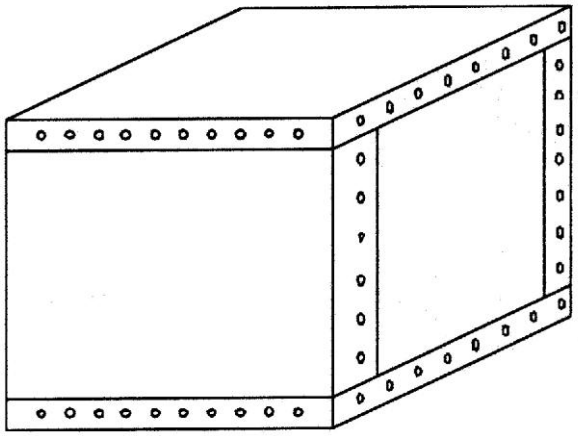
11. Ease of operating to its full rated capacity with the highest attainable economy.

12. Auxiliary equipment comprising the very best gauges, safety valves, and other fixtures.

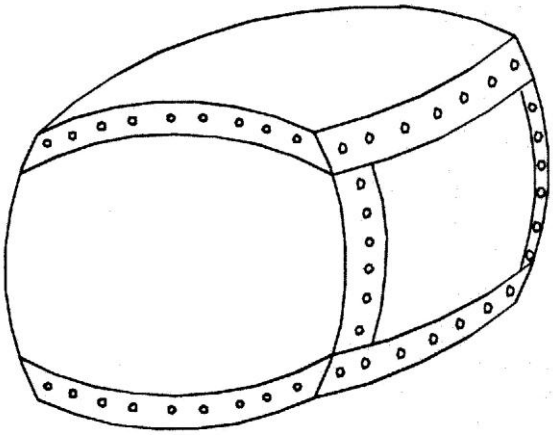
13. A setting that will ensure maximum efficiency of combustion and that will eliminate to the highest attainable degree, losses of heat by radiation and the loss of furnace efficiency by the infiltration of air.

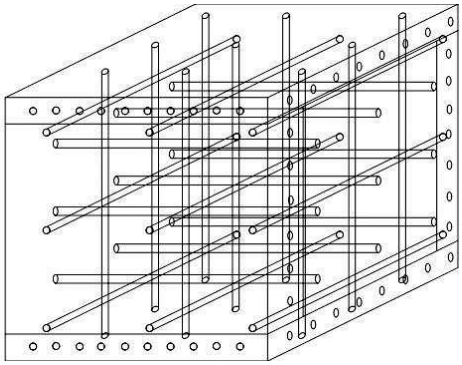
Note that the above requirements are based on the specific requirements of a perfect steam boiler which was prepared by G. H. Babcock and Steven Wilcox in 1875 and which has appeared in several editions of the book, Steam - its Generation and Use. Certain of the requirements have been modified in order to be more general rather than specific in scope.

Early Steam Boilers



The easiest way to make a boiler would be to take six flat sheets of wrought iron and rivet them together to make a cube. This would give you a large volume of water space and a flat surface to absorb heat from the fire. This allows the water to circulate freely through the boiler and there would be a large free area of water for the steam bubbles to disengage from the surface of the water. All the fittings would attach easily to the flat surfaces. Sounds good so far.

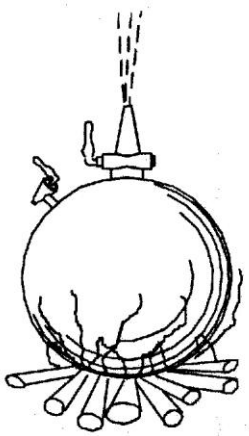




The problems with such a design become readily apparent if such a design were ever built. The twelve seams that formed the cube would bulge on all sides. Just as when you blow up a balloon the balloon forms a round shape, our boiler will also try to form a round shape. We could try to hold the sides of our cube flat by using stays (steel rods connecting sheets of steel together), but that presents another problem. By the time we put in all the stays to hold the front and back sheet, the left and right sheet, and the top and bottom sheet together, our boiler is now full of stays. There goes our good water circulation and the free area for the steam to leave the surface of the water. We could not get into our boiler to clean it because of the stays blocking all access inside the boiler, not to mention the added expense and trouble to install all the stays. Eventually our design would collect enough scale and mud on the bottom to cause the boiler to overheat and explode.

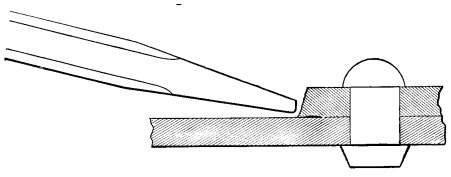
Why not make the boiler in a round shape in the first place so that it will not need stays, since the boiler is already in the shape that it is trying to assume due to the pressure inside.

This is exactly what early designers such as Raivault (1605), did.



There were many problems in building a large steam boiler in a round shape using small flat plates of steel. The plates had to be heated, hammered and riveted together into a round shape. Where the plates overlapped, the edges had to be beaten together with a hammer and a blunt nosed chisel known as a calking tool. This meant that the boiler had a great number of seams, each of which could spring a leak. Because the fire was at the bottom of the boiler, the heat would expand the plates on the bottom much more than the sides and top, increasing the likelihood of leaks.

Newcomen Boiler

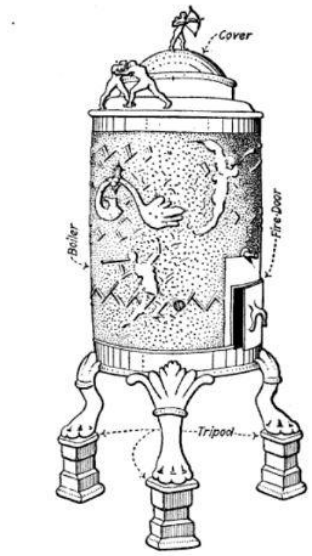


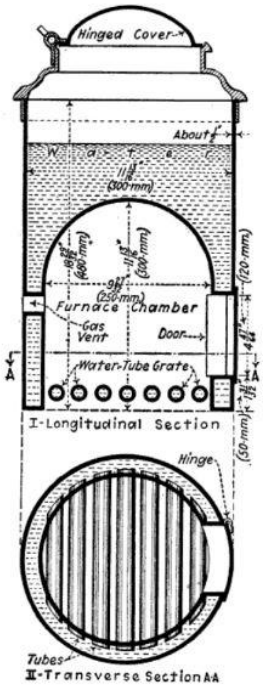
Calking tool for beating boiler plate until it is leak tight

Evolution of the Steam Boiler

Steam boilers are of ancient origin, they have been used for various services and in many forms since ancient times. It is desirable to consider for a moment some of the boilers of the ancient types so that the reader may be conversant with the evolution which has occurred.

The first boilers were in Greek and Roman origin. They were used several hundred years before the Christian era. They were small and were employed for warming water, for heating, and for household services.



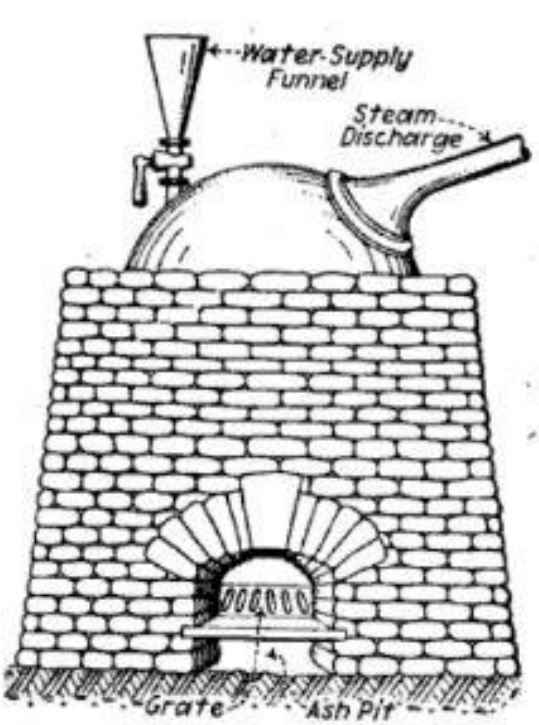


Pompeii was an ancient Roman town-city near modern Naples. It was destroyed and buried under 13 to 20 ft of volcanic ash and pumice in the eruption of Mount Vesuvius in AD 79. The boiler shown is from the ruins of Pompeii, and constitutes a typical example of the ancient boiler. It was of cast bronze and was evidently of the internally fired type. The grate comprises sheet bronze tubes opening and brazed into the water leg of the boiler. From this it is evident that the water-tube principle is an old one.

When in use, the boiler proper was supported on an ornamental tripod, which permitted the air required for combustion to enter from beneath. Three gas vents were arranged from the furnace chamber through the water leg to provide an exit for the products of combustion. The actual Pompeian boiler was embellished with finely wrought ornaments and miniature sculptures.

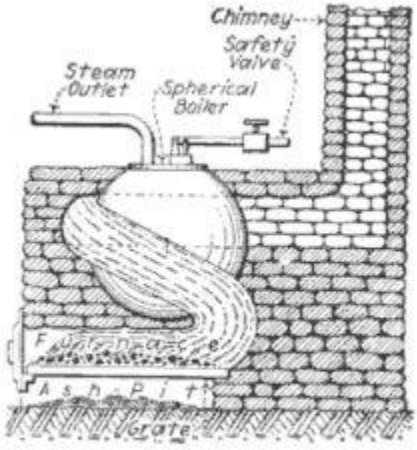
The boiler used with Hero's engine was the first recorded as to a mechanical work. It was made about 130 BC. The consist of nearly of a hemispherical cauldron of ornamental design which was heated by a fire arranged under it

Heroes engine was a hollow sphere, mounted and revolving on trunnions, having extended from it two nozzles with right angle turns at their ends. Steam from the boiler was admitted to the interior of the sphere through one of the trunnions. This steam issuing from the nozzles causes the sphere to rotate by virtue of the same principle as that on a lawn sprinkler.



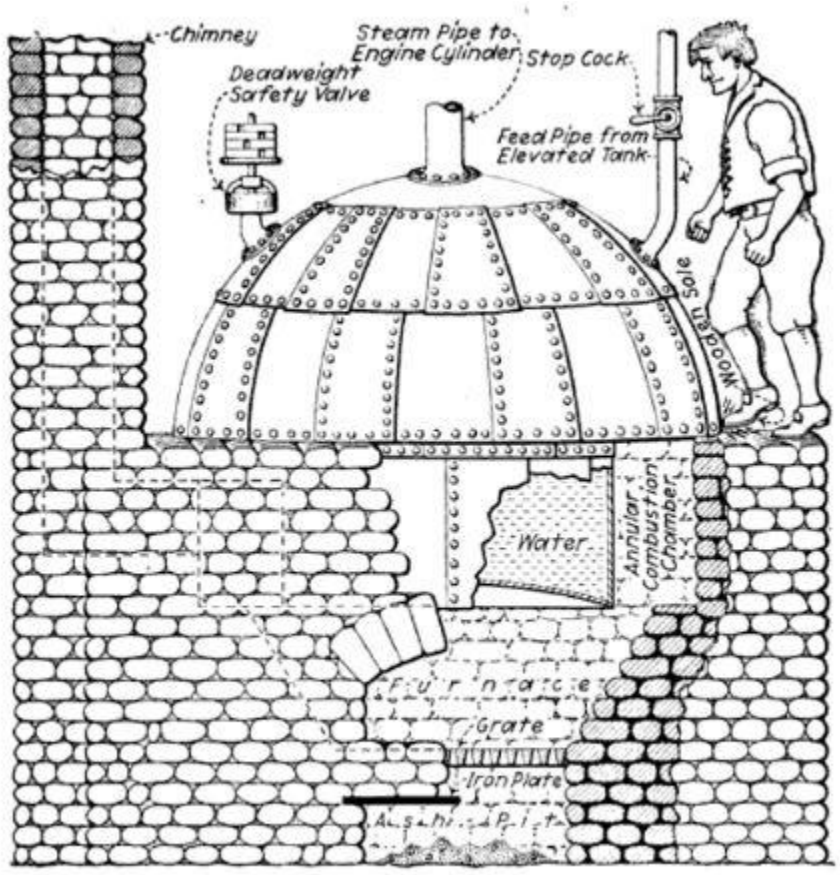
Savary's spherical boiler (year 1698).

Savary's boiler, so named after its inventor, was made in 1698. This apparatus utilized the phenomenon of both condensation and pressure for elevating water. The shell was spherical in shape. This is the first example of the application of a specially designed brick setting and furnace for a steam boiler. Savary improved boiler was constructed in 1702, and was an evolution from his original invention. In this boiler, the hollow cylinder had dished ends.



Desagalier's spherical boiler (year 1718).

Dr. Desagalier's spherical boiler was built in 1718. In this design, hot gases from the fire circulated in a spiral flue around the spherical water vessel. This marked an advance in furnace construction, since there was no attempt made in the designs of earlier boilers to guide the hot gases through paths where they would be the most effective in evaporating the water.



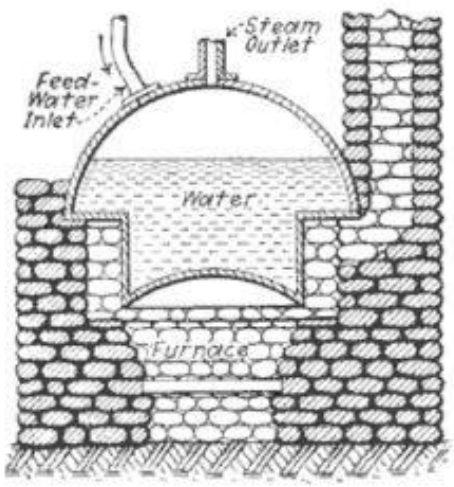
Newcomen's mushroom-shaped boiler.

The first boiler built for a practical purpose was built by Thomas Newcomen in 1705. Newcomen's mushroom boiler was the first real steam generator. It was built in 1705 and was used to generate steam for Newcomen's atmospheric engine. Previous inventors had generally used the spherical form of vessel as affording maximum strength. The engine developed by Newcomen was operated with steam at a very low pressure. He was able to depart somewhat from the spherical form. Hence, he designed a boiler that would give a greater proportional area to the heating surface to ensure better economy.

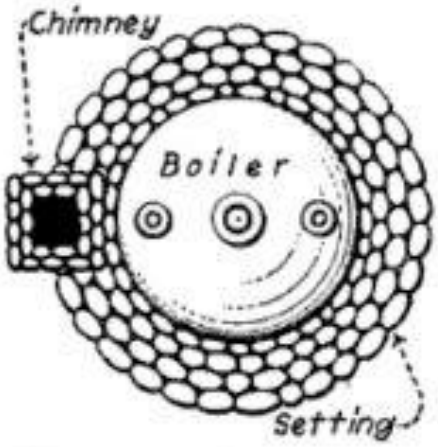
The accessories of these primitive boilers included a dead weight safety valve. But they were often without the gauges for indicating the water level in steam pressure. The height of the water in the boiler was determined by the sound, hollow or otherwise, as given out by the boiler sheets when struck with a club or kicked with a wooden soled shoe known as a brogan worn by the attendant. The simmering of the safety valve indicated when the fire was sufficiently hot. The steam outlet was in the crown of the dome.

. Newcomen was an Englishman who built the boiler to power his steam engine. The steam engine was built to pump water out of the coal mines so that the miners could dig the coal seams that lay deeper in the Earth. The reason that England started what was known as the "Industrial Revolution" was that it had the raw materials, iron and coal, and the genius of several inventors working at the same time to create the machinery to build the products needed to turn England from a farming culture into a society based on manufacture and trade.

The water was fed and from an elevated tank by gravity. A round manhole, which had its cover fastened on the outside with stud bolts, was provided in the dome.

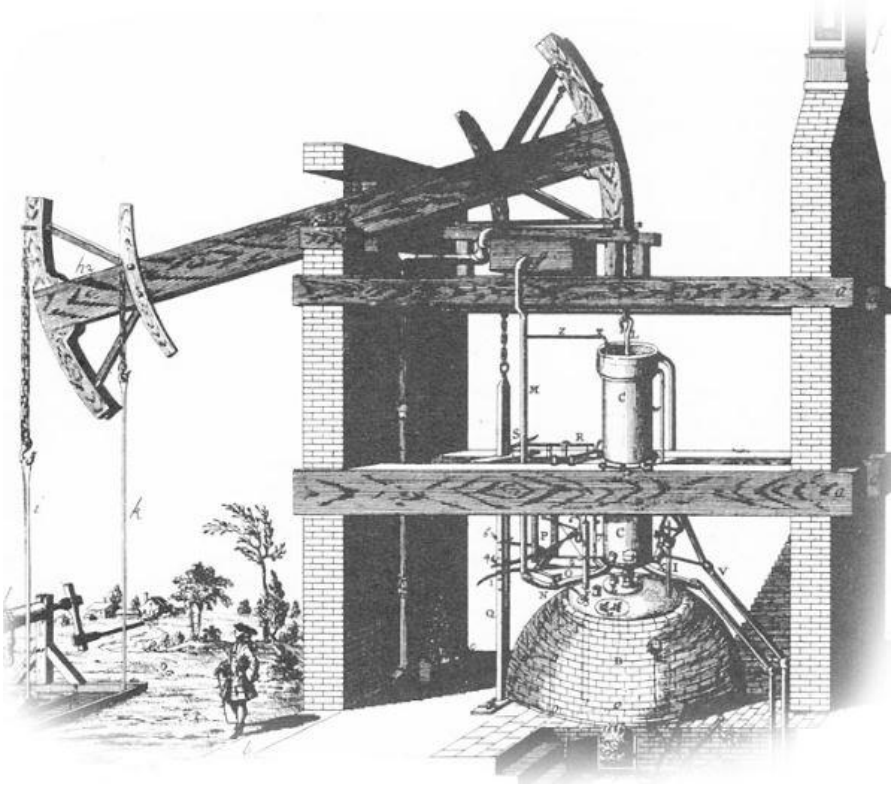


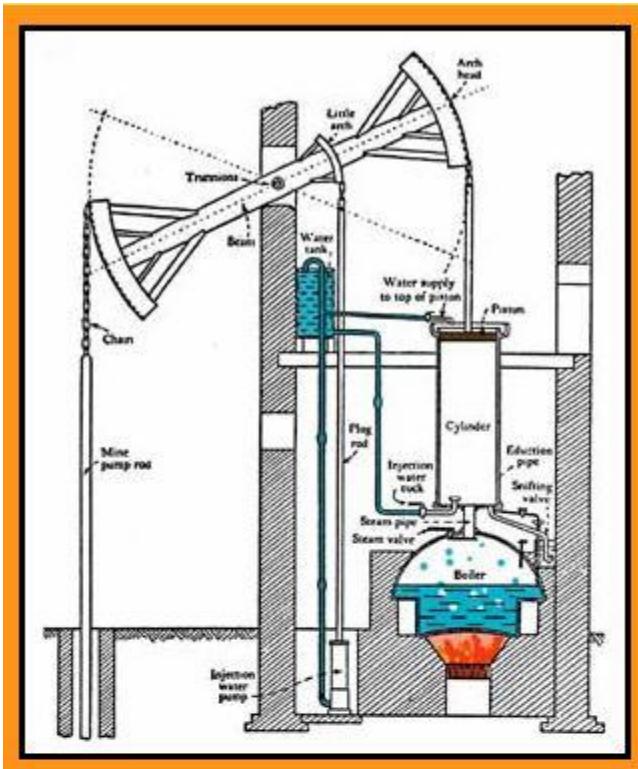
Section of Newcomen's boiler and setting (year 1705).



Top view of Newcomen's mushroom-shaped boiler.

The upper half of the boiler was hemispherical. The lower half was cylindrical with a concave furnace or crown sheet. The spherical dome overhung the cylindrical shell beneath. It provided a means of suspension in the setting which permitted the arrangement of an annular combustion chamber around the shell. This boiler was, presumably braced with some sort of diagonal or gusset stays which secured the flat ring or base sheet to the dome.

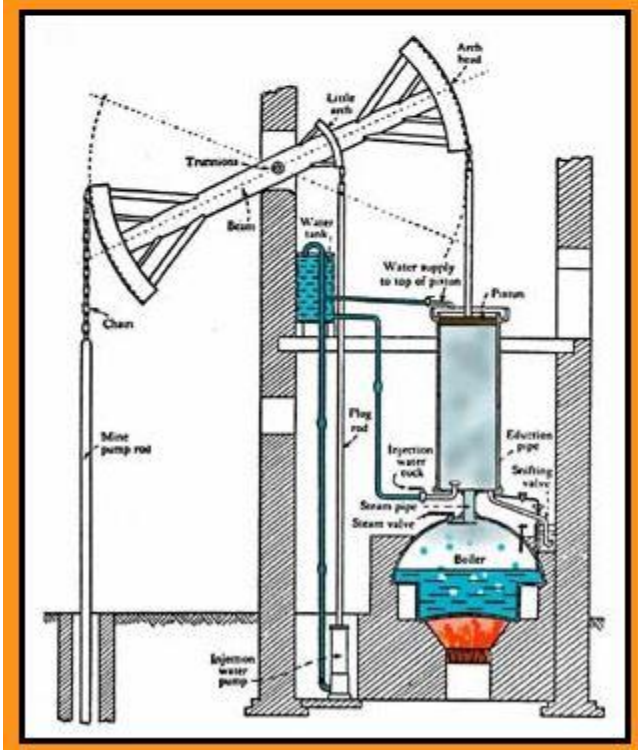




Newcomen's Engine

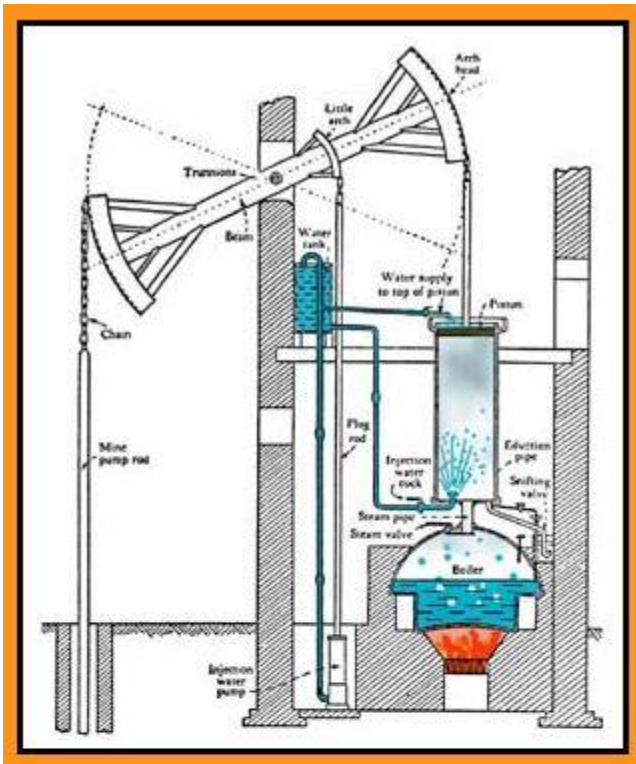
The **Boiler** continuously generates steam.

The **Piston** is kept up at the top of the **Cylinder**--NOT by pressure from the steam, but by the fact that the **Mine-Pump-Rod arm** of the **Beam** (left) weighs more than the **Piston arm** (right).



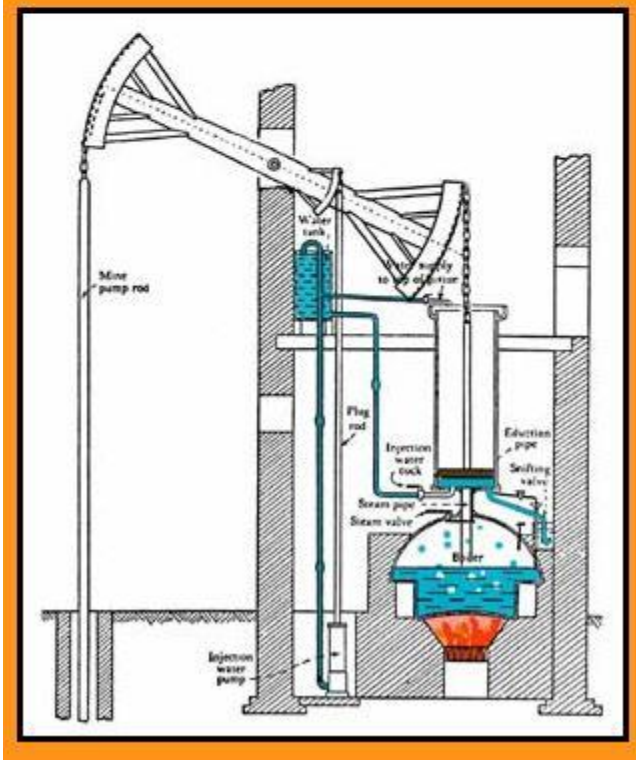
When the valve above the **Boiler** is opened, steam enters and fills the **Cylinder**.

The **Piston** remains at the top of the **Cylinder** due to the unequal distribution of weight on the **Beam**.



The **Boiler** valve is closed, trapping the steam in the **Cylinder**.

The accident that destroyed his early engine taught Newcomen a valuable lesson about steam. He changed his engine design in order to optimize the power that could be gained from the **Piston**'s downstroke. Instead of cooling the **Cylinder** gradually by spraying its exterior as Papin and Savery had done, Newcomen inserted a pipe to spray cool water inside the **Cylinder** to condense the steam rapidly.

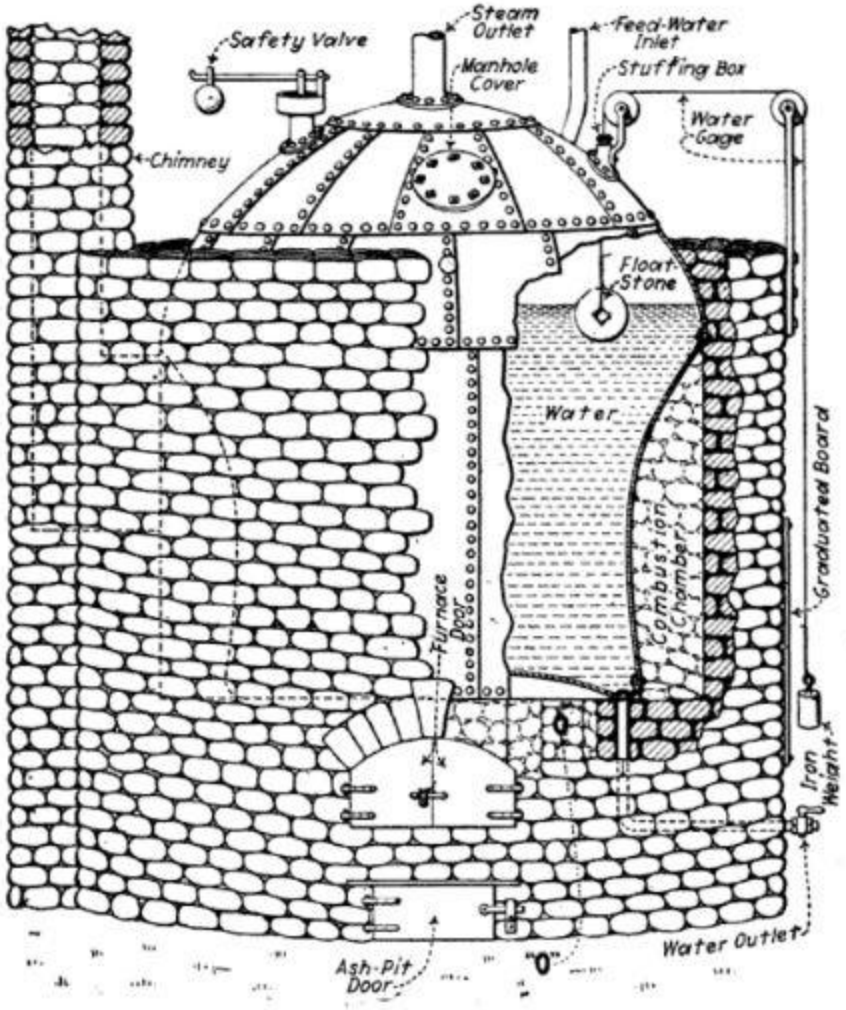


When the steam condenses, there is very little pressure left in the **Cylinder** to resist the force of the atmosphere above the **Piston**.

As the **Piston** is pushed downward by the atmosphere's pressure , it pulls the **Piston arm** of the **Beam** down with it. This action lifts the **Mine-Pump-Rod arm** of the **Beam**.

The engine was able to operate at a rate of 15-16 cycles per minute.

The Haystack boiler came into use about the middle of the 18th century. This was introduced by John Smeaton and was a modification of the mushroom boiler. It was designed to provide greater strength. This was done by eliminating the flat ring sheet which formed the base of the dome, and by approaching throughout the spherical form. Its setting was similar to that of the mushroom boiler. An exception was at the furnace wall was drawn in near the bottom, to permit the flange of the crown sheet to sustained the entire weight. Access from the furnace to the annular combustion chamber was provided by three or four openings in the masonry.

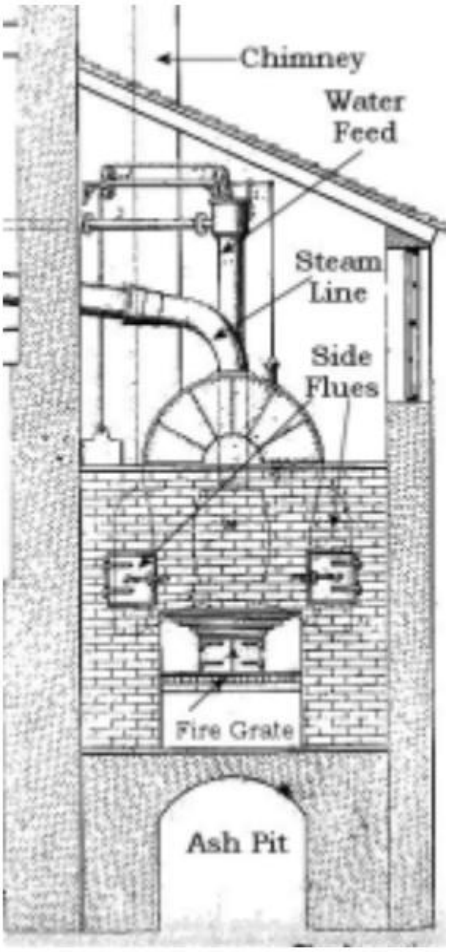


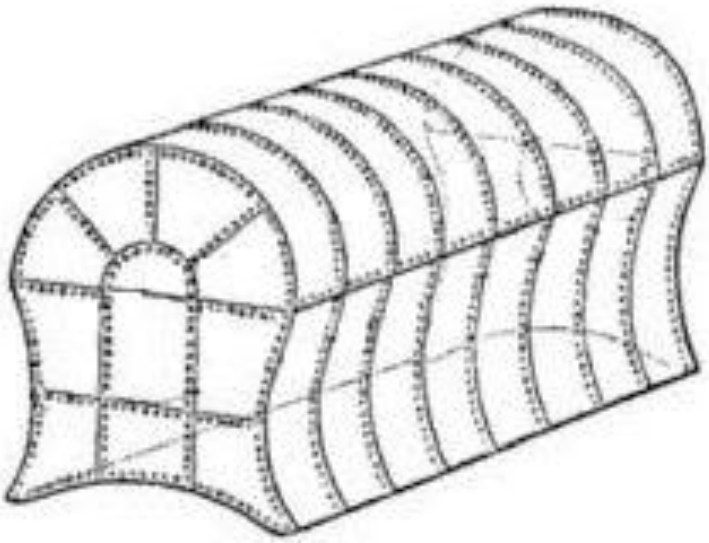
Haystack boiler.

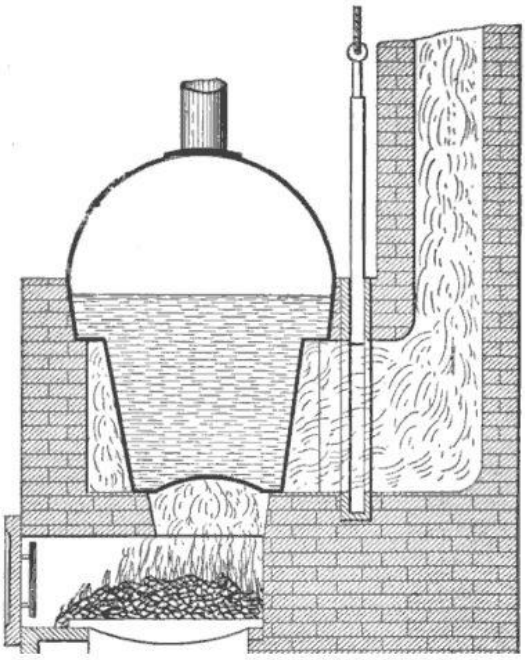
These Haystack boilers were sometimes braced by tying the dome sheet to the furnace sheet with through tension rod stays. But they were generally constructed without stays. Many boilers of this type continued in use in England through the first quarter of the 19th century. The equipment of the Haystack boiler shows improvement over that of its predecessor. The accessories include a ball and lever safety valve and a float stone for showing the water level. A "float stone" consisted usually of a worn out grindstone hanging on a copper wire on the inside of the boiler. The wire passed out through a stuffing box and ran over to police to an iron weight. The stone rose and fell with the water level. The height of the water was indicated by the position of the weight in relation to graduations on a board in front of which the weight traveled up and down. The blowdown pipe, with a stopcock, was also provided.

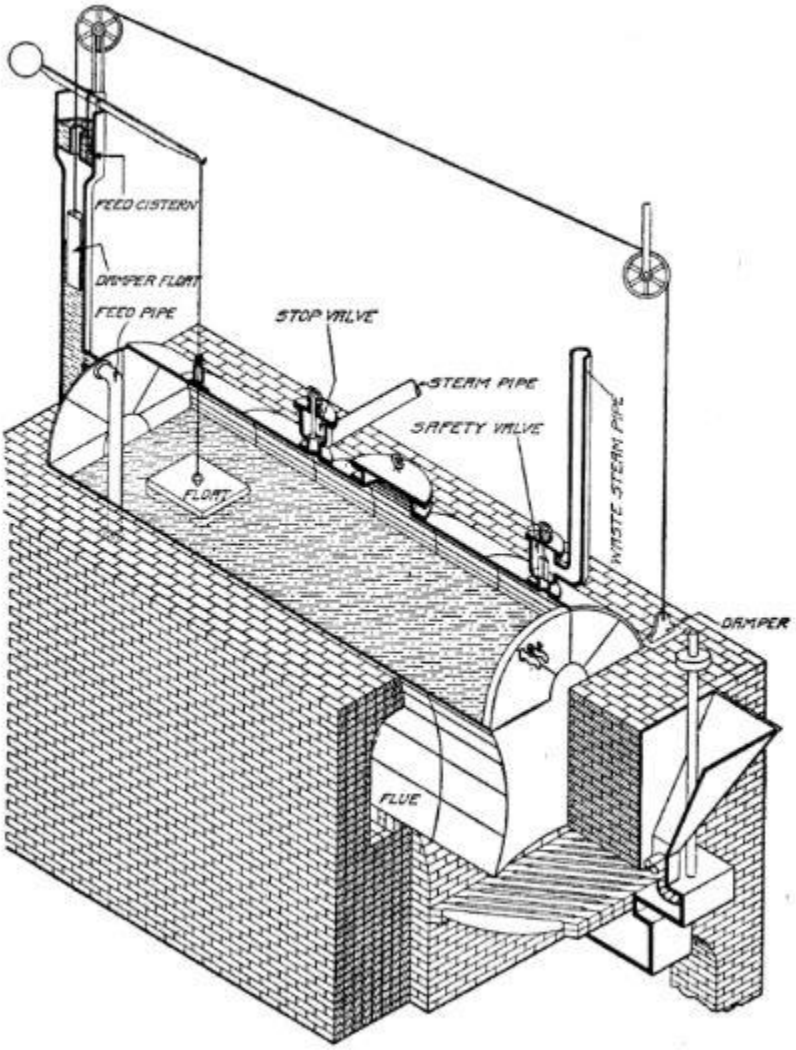
James Watt (1736 - 1819) was a Scottish inventor, mechanical engineer, and chemist whose Watt steam engine, an improvement of the Newcomen steam engine, was fundamental to the changes brought by the Industrial Revolution in both his native Great Britain and the rest of the world. There is a popular story that Watt was inspired to invent the steam engine by seeing a kettle boiling, the steam forcing the lid to rise and thus showing Watt the power of steam.

James Watt's wagon boiler was the first radical department from the spherical form. This boiler was designed by James Watt in about 1765. The upper half of this boiler was semi-cylindrical. The lower half was a box shape with concave sides. The bottom was concave and the ends were flat.

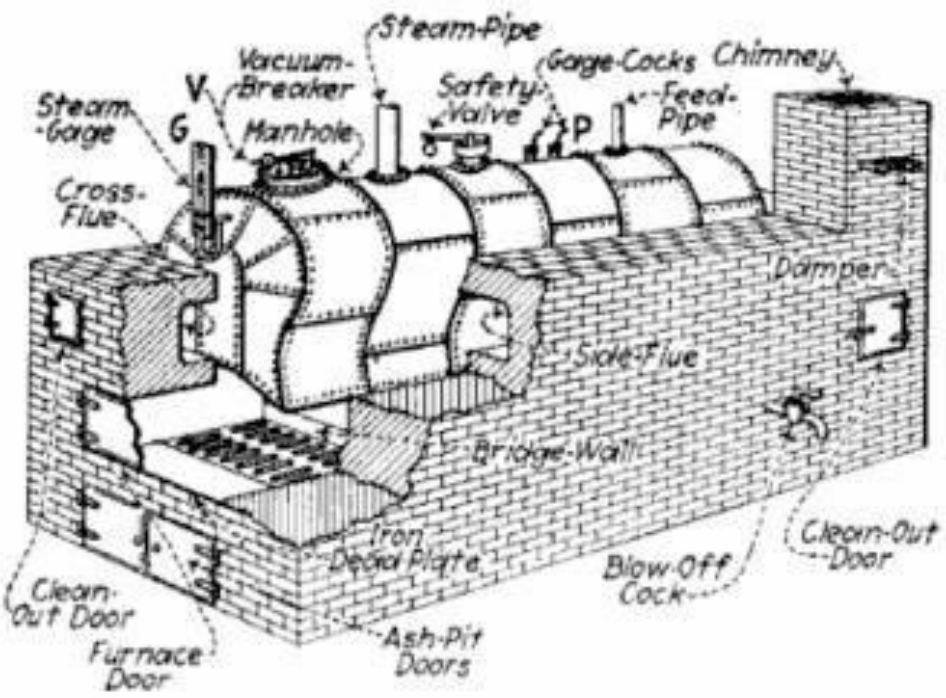








The masonry was closed in at the upper and lower edges of the concave side sheets, so as to form flues along the sides. The two side flues were joined at the front by a duct which was hollowed out in the masonry. They were separated at the back by a baffle wall that divided the chimney from the back connection. The products of combustion swept along the bottom sheet to the back end and returned through a side flue to the front end, crossed to the opposite side flue and passed out to the chimney.



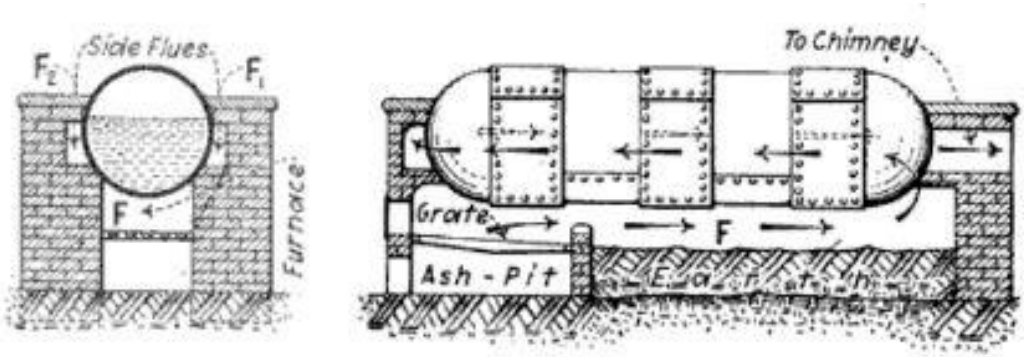
Watt's Wagon Top Boiler

It is probable that these wagon boilers were sometimes braced by tying the side sheets together with stay rods but they were generally built without braces of any kind. None of them could handle safely a pressure in excess of about 10 PS I.

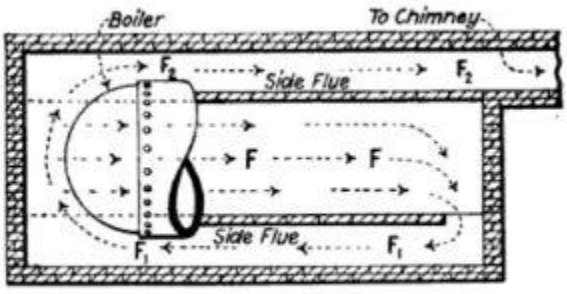
The accessories of Watt's boilers included some appliances which were absent in the designs devised by his predecessors or which were used by them in cruder forms. Notable among Watt's fittings are the steam gauge, the water gauge cocks and the pipes and the vacuum breaker. The steam gage was merely a Brass U- shape tube screwed into the front end of the boiler shell. It contained a quantity of mercury. A wooden float which was carried on the surface of the mercury rose and fell with the mercury column and the outer leg of the U-tube. The pressure was indicated on a graduated scale which was attached to the tube. The water gauge pipes extended down into the boiler. The upper one terminated in the steam space an inch or two above the proper water level. The lower end of the other one extended into the water space to a depth of about 2 inches below the normal water level.

A vacuum breaker was a valve which opened inwards. It was designed to prevent collapse of the structure by the external pressure of the atmosphere when, after being in service, a boiler was permitted to cool down.

The egg end or cylindrical boiler was the next development. With the extended use of steam power during the closing years of the 18th century there was a corresponding increase in the pressure required for newer applications. Coincidentally there developed of demand for stronger steam generating apparatus. About this time the oddly shaped shell of the wagon top boiler lost its vogue and was superseded by the shell of cylindrical form. Furthermore, the flat wrought iron head sheets of the wagon boiler were displaced by thick hemispheric cast iron heads which tended to provide a boiler of somewhat oval or egg form. However, in its settings and accessories the egg end boiler retained all of the essential characteristics of its immediate predecessor - the wagon top. These inherited features include the arrangement of the side and cross flue for creating a "wheel draft," as the circuit of the furnace gases around the boiler was termed.

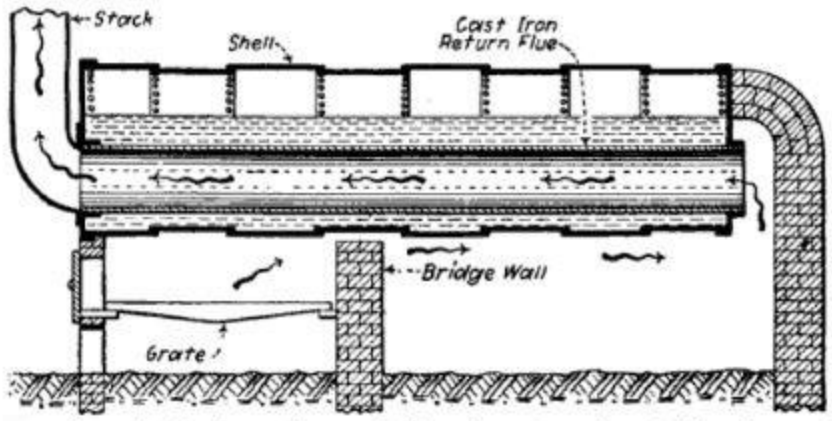


The egg-end or cylinder boiler (year 1790).



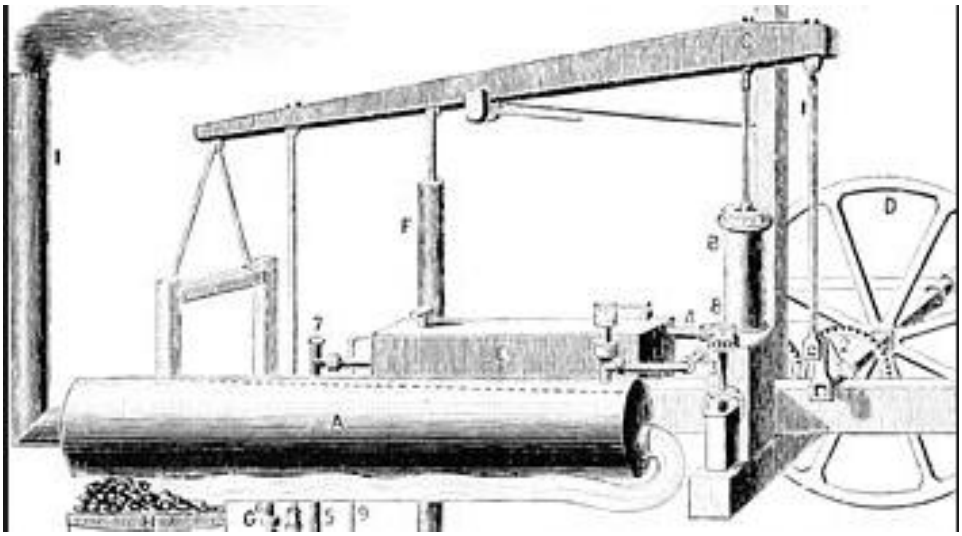
Wheel-draft circuit of the egg-end boiler.

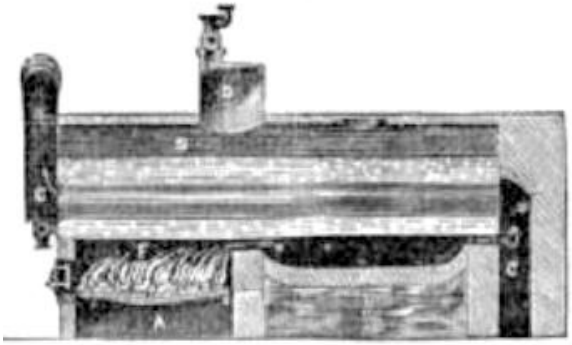
The idea of putting the return flue inside the shell of the boiler instead of running it around the outside was first conceived by an American engineer, Oliver Evans.



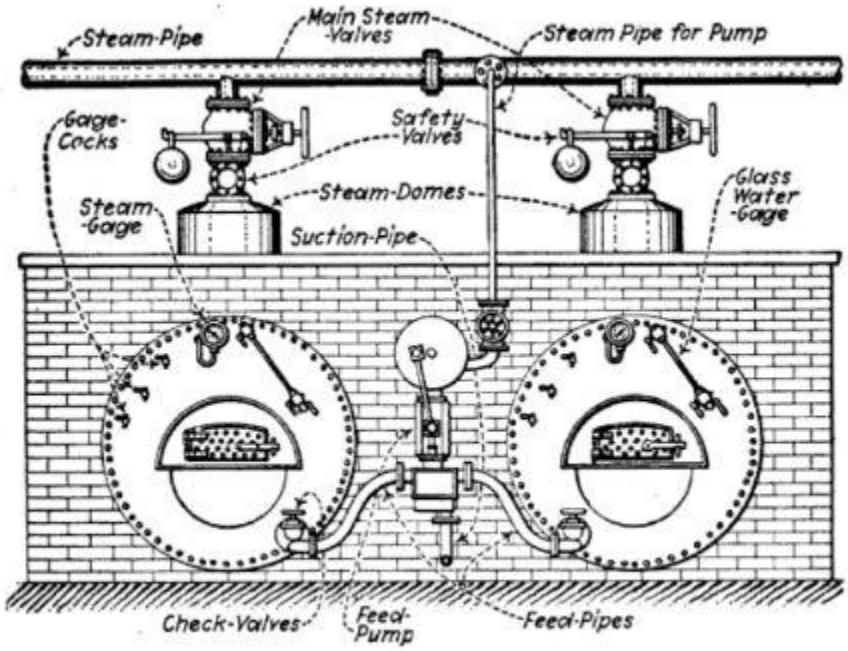
Longitudinal section of Evan's return-flue boiler (year 1800).

His invention was a direct forerunner of all subsequent designs of horizontal return tubular and flue boilers. Some of these boilers made in about the year 1800 had cast iron shells and wrought iron flutes. The diameter of the flue was usually about half of the boiler shell diameter.





The Cornish boiler was designed by Richard Trevithick, an English engineer connected with the Cornish mining industry, and was a result of a plan to improve boiler economy. Trevithick proposed to locate the furnace inside the flue. The original Cornish boiler, thus invented by Trevithick, may be regarded as a forerunner of all internally fired boilers of subsequent types. The boiler was bill with a single flue sufficiently large to hold a furnace having a grate area proportioned properly to the available heating surface. The furnace was made by mounting the grate bars on bearing bars, which were secured crosswise to the flue at the front and rear ends of the furnace. A bridge wall to hold a fire on the grate and to form an ash pit was erected at the rear of the furnace.



Front-end view of a pair of Cornish boilers.

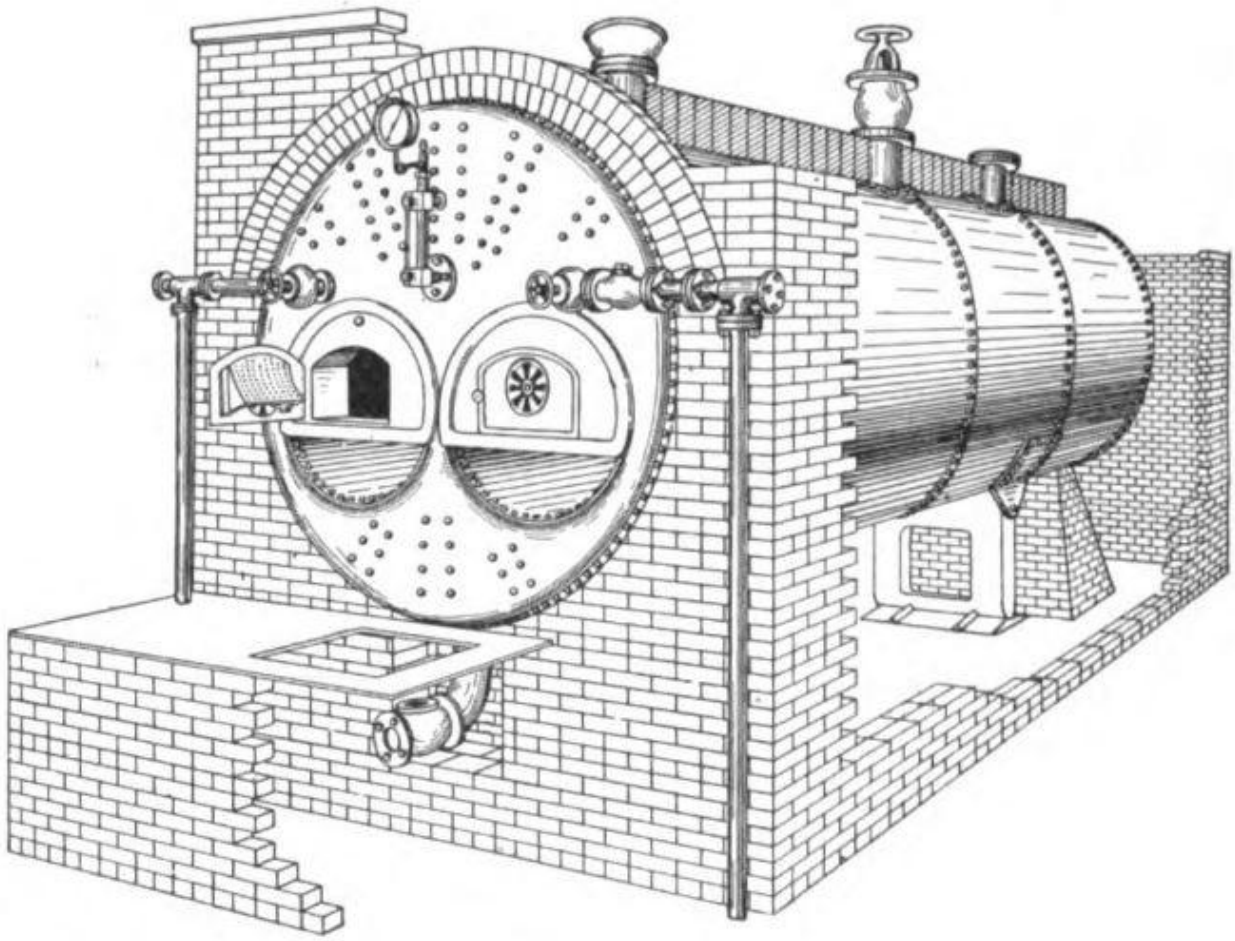
Cornish boiler

The Lancashire boiler is similar to the Cornish, but has two large flues containing the fires instead of one. It is generally considered to be the invention of William Fairbairn in 1844,

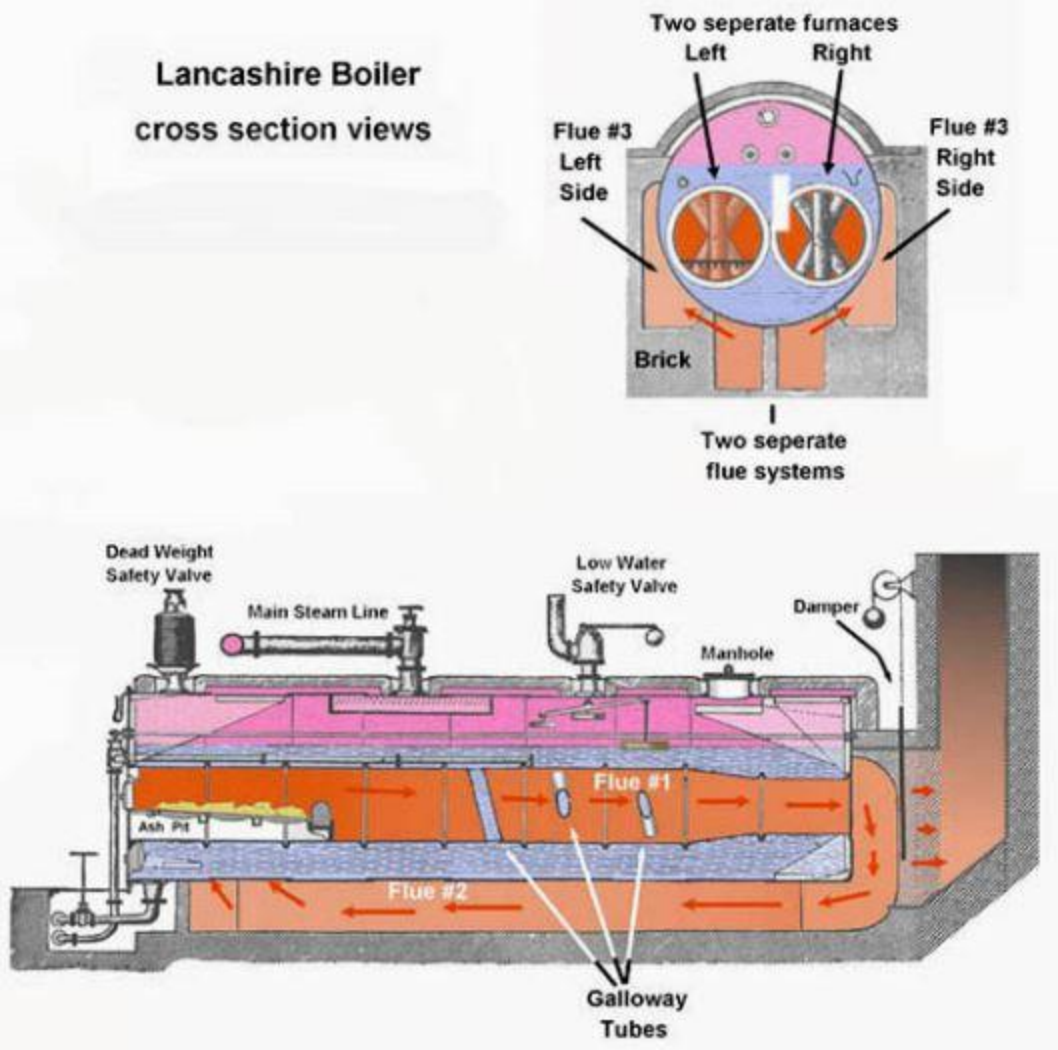
Fairbairn had made a theoretical study of the thermodynamics of more efficient boilers, and it was this that had led him to increase the furnace grate area relative to the volume of water. A particular reason for this was the so-far poor adoption of the Cornish boiler in the cotton mills of Lancashire, where the harder local coal couldn't be burned satisfactorily in the smaller furnace, in favor of the older low-pressure wagon boiler and its large grate.

The difficulties of the Cornish boiler were that a boiler of any particular power would require a known area of furnace tube as the heating area. Longer tubes required a longer and more expensive boiler shell. They also reduced the ratio of grate area relative to the heating area, making it difficult to maintain an adequate fire. Increasing the tube diameter reduced the depth of water covering the furnace tube and so increased the need for accurate control of water level by the fireman, or else the risk of boiler explosion. Fairbairn's studies of hoop stress in cylinders also showed that smaller tubes were stronger than larger tubes. His solution was simple: to replace one large furnace tube with two smaller ones.

The patent showed another advantage of twin furnaces. By firing them alternately and closing the firebox door between firings, it was also possible to arrange a supply of air past the furnace (in the case of a Lancashire boiler, through the ashpan beneath the grate) which would encourage the flue gases produced by the fire to burn more completely and cleanly, thus reducing smoke and pollution. A key factor in this was the distinctive shuttered rotating air damper in the door, which became a feature from the 1840s.



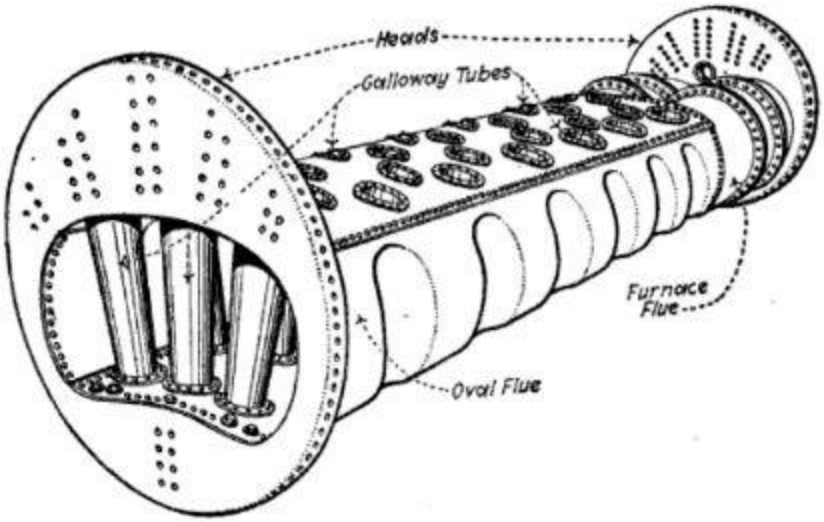
The use of two flues also has a strengthening effect, acting as two long rod stays that support the end plates.



The Lancashire was similar to the Cornish boiler except that it had two hand fired coal furnaces in the shell rather than one. This allowed the Boiler Operator to clean the fire in one furnace while maintaining steam pressure with the other. Lancashire boilers were named for the area in which they were extensively used, Lancashire England, which was the center for the textile industry in the 1800's.

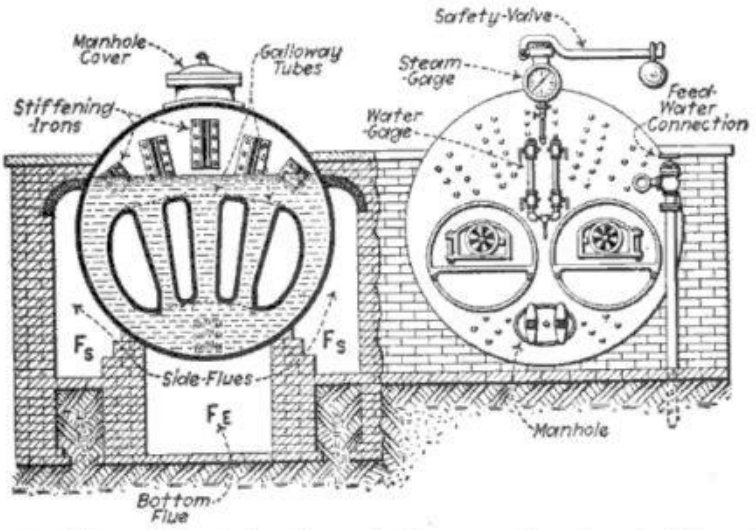
In the Lancashire Boiler first coal is fed on the grate where combustion of coal takes place. The Flue gases pass through the internal flue tubes and then pass downwards. The flue gases travels through the bottom flue to the front of the boiler. Then they are split up into two streams and flow through the side flues to the rear end of the boiler. Flue gases then pass through the dampers into the main flue and are finally discharged through the chimney into the atmosphere. The heat of flue gases is transferred to the water to generate steam.

Although the Lancashire boiler is considered to be an antiquated design, provided that the flue is long enough it can be reasonably efficient. This does lead to a bulky boiler though, particularly for its length, and this has always limited its use to stationary installations. It was the standard boiler in Greater Manchester and Lancashire cotton mills.



Galloway boiler with outer shell removed.

Later developments added Galloway tubes (after their inventor, patented in either 1848. crosswise water tubes across the flue, thus increasing the heated surface area. As these are short tubes of large diameter and the boiler continues to use a relatively low pressure, this is still not considered to be a water-tube boiler. The tubes are tapered, simply to make their installation through the flue easier.



Views of front elevation and of cross-section through kidney flue of Galloway boiler.

Lancashire boilers often show corrugated flues, which absorb thermal expansion without straining the riveted seams. Another development was the "kidney flue" or Galloway boiler, where the two furnaces join together into a single flue, kidney-shaped in cross-section. This widened and flat-topped flue was stayed by the use of Galloway tubes.

Due to the success of the Cornish and the Lancashire boiler, it was found that if you increased the number of flues in the boiler, you could increase the efficiency. This continued until the more modern types of boilers were developed with many tubes in the boiler rather than a few flues. A flue is defined as any fire tube over four inches in diameter. If it is less than four inches in diameter, then it is called a tube. Tubes are measured by their outside diameter.

Chapter 2 Questions

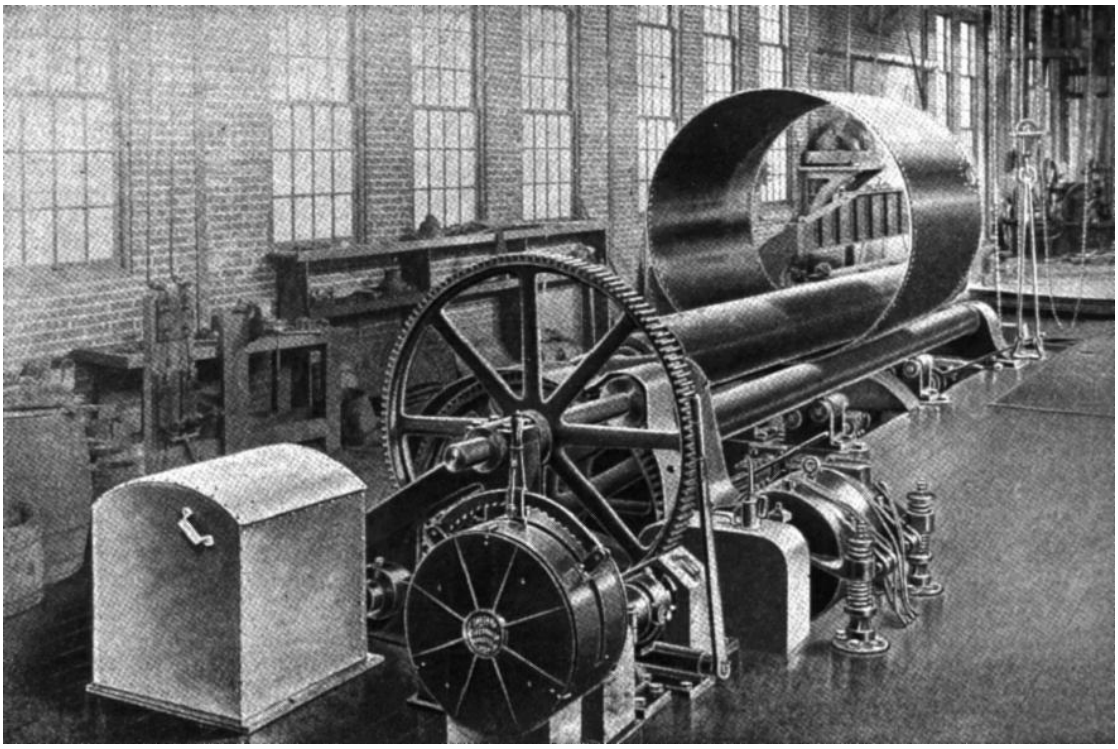
1. Who built the first boilers?
2. Who built the first boiler used for a practical purpose? What did he use his boiler for?
3. How did the early Operators tell where the water level in the boiler was without a sightglass or other level indicator?
4. Who built the first haystack boiler? What did his boiler have that Newcomen's did not?
5. Name the improvements for boilers that James Watt invented.
6. What type of boiler did Oliver Evans invent?
7. How does Oliver Evans' boiler differ from the Cornish boiler?
8. What is the difference between the Cornish and the Lancashire boiler?

Newcomen Boiler at The Henry Ford Museum

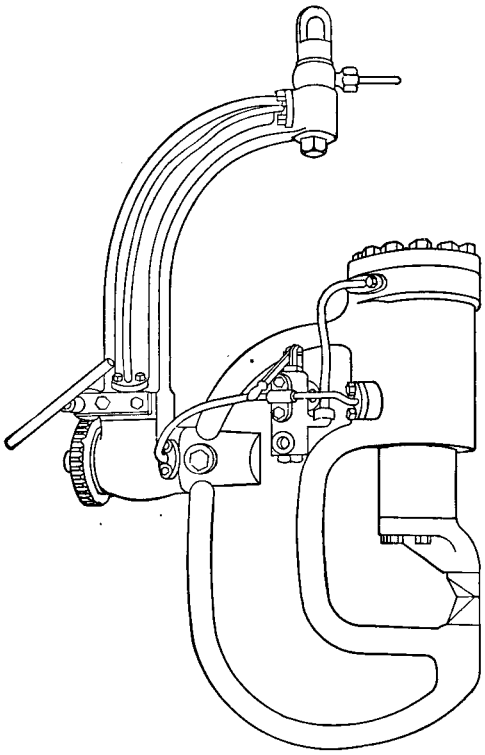
Chapter 3 Riveted Boilers

RIVETED BOILERS

Modern boilers are no longer riveted as they once were. The holes drilled through the plates for the rivets, weakens the plate. Fusion welding is a superior method of joining the plates of mild steel that make up the boiler. Some license examinations still ask questions about riveted boilers and there are still riveted boilers in use, so we will devote some time in discussing them.



In riveting a boiler, the plates of steel were rolled into a circular shape and then holes were either drilled, punched and drilled, or drilled and reamed to the desired size. The Code requires that the holes may be punched if the material is less than 5/16 of an inch thick and the hole is at least 1/8 inch diameter less than the final diameter of the drilled hole. If the material is over 5/16 of an inch thick, then the hole must be at least 1/4 inch diameter less than the final diameter of the drilled hole. The holes are punched with a hydraulic press. The ASME Code does not allow punching of holes in material over 5/8 of an inch thick. The parts are bolted in position before the final drilling to ensure that the holes line up and are concentric.



Riveter for Boiler Manufacture

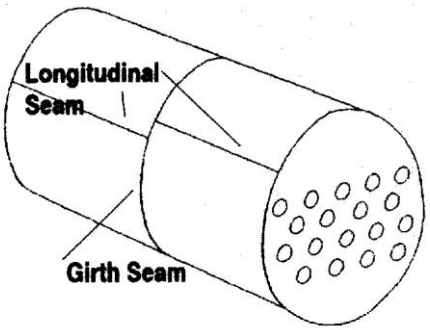
Factory machine riveter in use

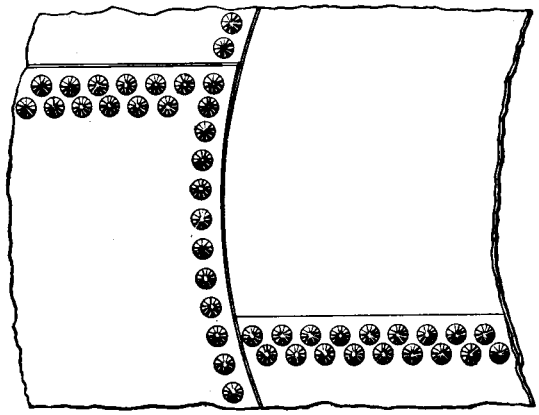
The preferable method of riveting was to use a hydraulic riveting machine that held the red hot rivets under pressure until they had cooled. Other accepted methods were hand riveting and using a pneumatic hammer.

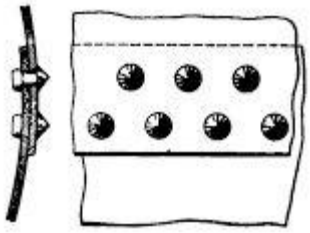
Oven for heating rivets

Pneumatic riveter and buck

The bucking tool acts as an anvil for the pneumatic riveter in the foreground

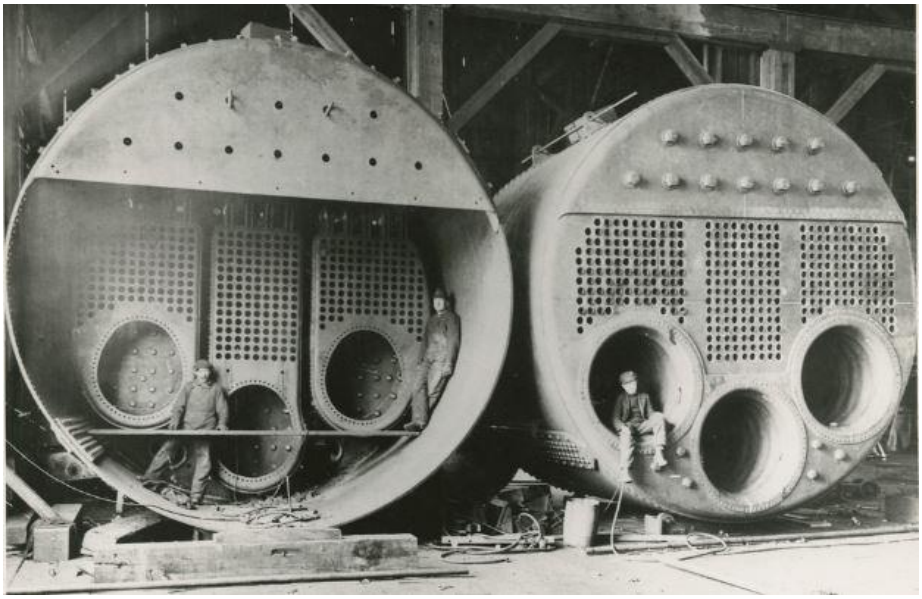






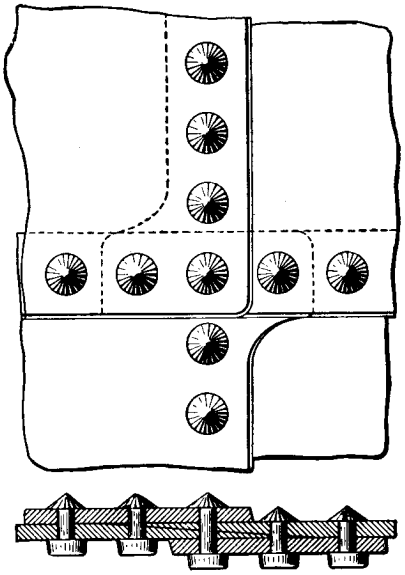
Lap Joint

The circular seam that goes around the boiler is known as the girth seam. The seam that runs the length of the boiler is known as the longitudinal seam. The force that tries to rupture the boiler along the girth seam is one/half the force that tries to rupture the boiler along the longitudinal seam. That means that the girth seam is inherently twice as strong as the longitudinal seam. Since the longitudinal seam is one/half as strong as the girth seam, the longitudinal seam is made twice as strong as the girth seam so that both seams can withstand the same pressure.



The bigger the diameter, the more stress is put on the boiler shell. As the boiler diameter gets bigger, the boiler steel must get thicker in order to handle the added stress. There is a limit to how thick a boiler shell can be made and still be able to have the water inside the boiler cool the boiler steel. This is why there is a definite limit to how large a fire tube boiler can be made. For fire tube shell type boilers, that limit is a diameter of around 96 inches and a pressure of around 200 psi.

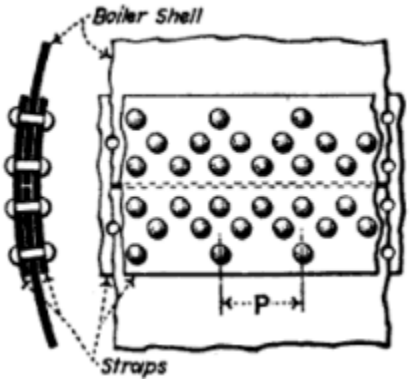
Lap joints are made when the boiler plates overlap and are riveted together. Lap joints are not permitted if the boiler is over 36" and operated at over 100 psi. The reason is that a boiler with lap joints can never form a true circle on the inside, although the pressures on the inside will try to force it into a true circle, so it is an inherently weak joint.

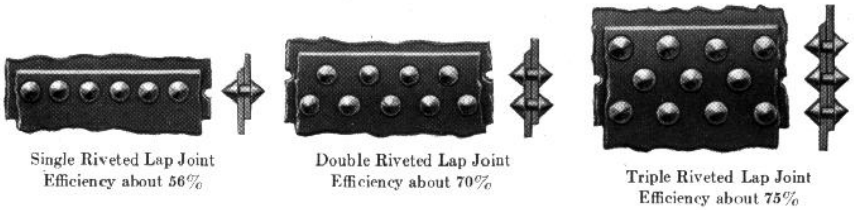


A butt joint is made when the two plates of steel are rolled to form a true circle. Obviously the plates cannot overlap so a strap of steel must run the length of the seam on the outside and overlap both plates. The rivets are then driven through the strap of steel on both sides of the seam and through both plates on each side of the seam. To further increase the strength of the joint, a strap of steel can be placed on the inside of the seam as well as the outside. The rivets then go through the two straps of steel and the boiler plate which is sandwiched between the two straps of steel.

Efficiency of a riveted joint is the percentage of the strength of the riveted joint to the solid plate that the boiler is constructed from. Efficiency of the various riveted joints is as follows:

1. Single riveted lap joint.....55%
2. Double riveted lap joint.....70%
3. Triple riveted lap joint.....75%
4. Single riveted butt joint.....65%
5. Double riveted butt joint.....80%
6. Triple riveted butt joint, straps equal width.....83%
7. Triple riveted butt joint, inside strap wider.....85%
8. Quadruple riveted butt joint, inside strap wider.....90%
9. Quadruple riveted butt joint, sawtooth straps.....93%



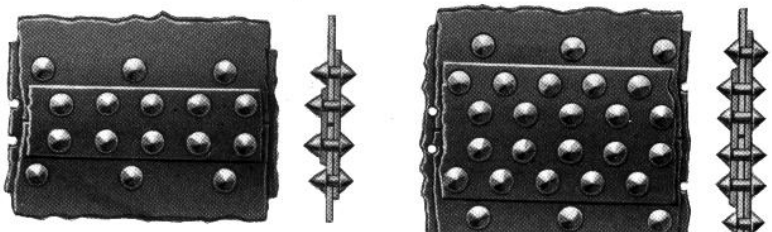


Single Riveted Lap Joint
Efficiency about 56%

Double Riveted Lap Joint
Efficiency about 70%

Triple Riveted Lap Joint
Efficiency about 75%

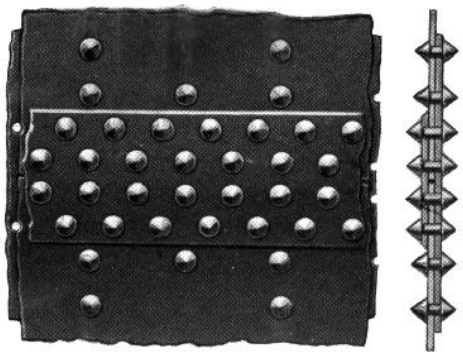
A single riveted joint has two rows of rivets, one on each side of the seam. A double riveted joint has four rows of rivets. A triple riveted joint has six rows of rivets. A quadruple riveted joint has eight rows of rivets.



Double Riveted Butt Strap Joint
Efficiency about 82%

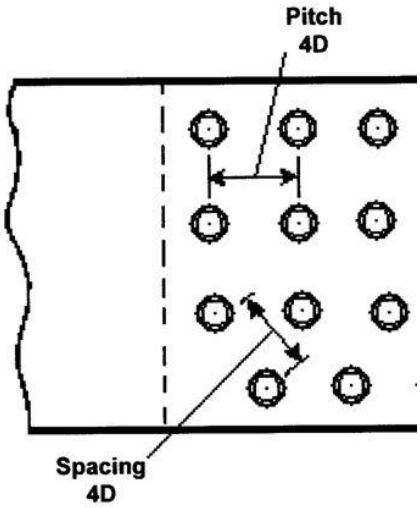
Triple Riveted Butt Strap Joint
Efficiency about 86%

If a lap riveted boiler is over 20 years old and was operated at pressures over 50 psi, the boiler must be de-rated to operate at pressures under 50 psi.



Quadruple Riveted Butt Strap Joint
Efficiency about 94%

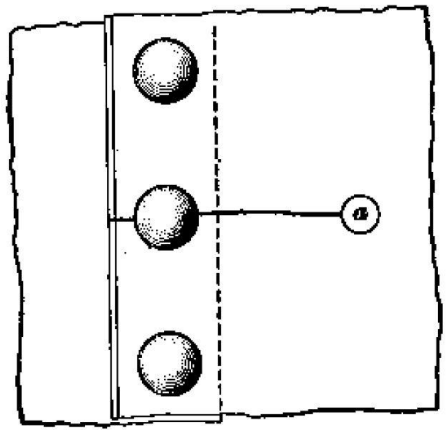
A butt riveted boiler over 25 years old must have a hydrostatic test to determine whether it is safe to operate. The pressure that the boiler operates at may have to be lowered in order to increase the factor of safety of the boiler.



The pitch of the rivets is the distance between the center of one rivet to the one next to it.

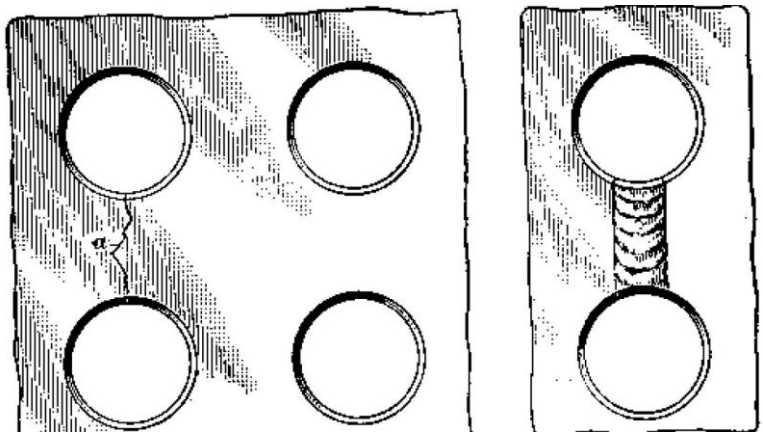
The factor of safety is the pressure at which the boiler will burst divided by the maximum allowable working pressure. By lowering the maximum allowable working pressure you increase the factor of safety. The factor of safety of older boilers is 5. That means if the bursting pressure of the boiler is 500 psi, the highest pressure the boiler can be operated at is 100 psi. As the boiler gets older, the inspector will lower the maximum allowable working pressure in order to ensure that the boiler is safe to operate. The maximum life of a boiler is usually figured at 40 years but with good water treatment, life extension programs and proper inspection service, boilers can be run for many more years.

Modern welded boilers have a factor of safety of 4. This is due to the confidence of the American Society of Mechanical Engineers in today's welding and inspection methods.



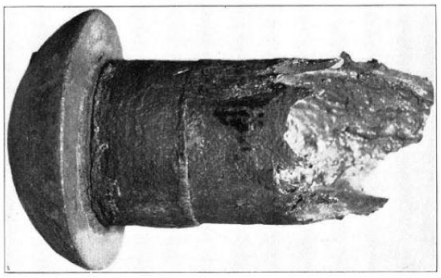
Riveted boilers can develop cracks in the boiler steel that start from the rivet holes. If the crack extends from the rivet hole to the edge of the plate, then it is called a fire crack. The inspector will allow a boiler to continue to operate with a certain number of fire cracks. This crack can be repaired in the following manner:

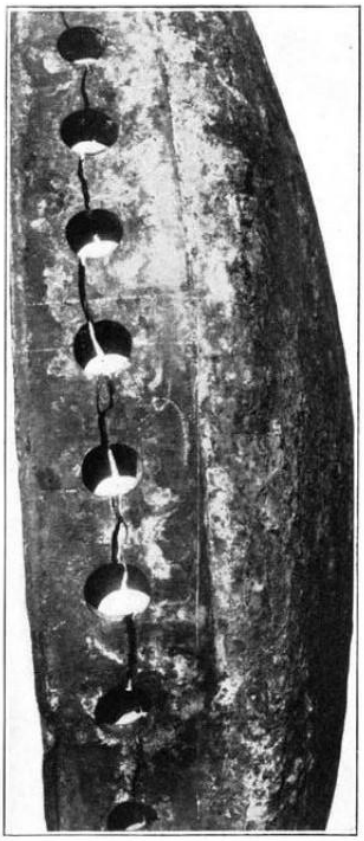
1. Take the boiler out of service
2. Remove the rivet from which the crack begins
3. Grind out a "V" in the crack
4. Weld the crack using an A.S.M.E. approved welder
5. Grind the weld flush with the surface of the boiler plate
6. Ream the rivet hole to the correct size
7. Replace the rivet

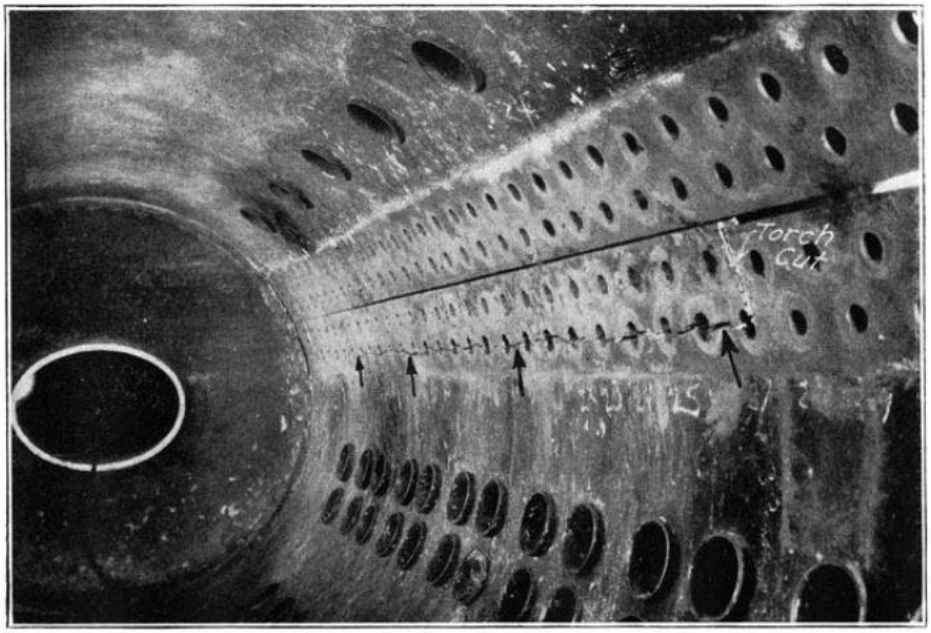


Longitudinal seam cracks from rivet to rivet cannot be repaired by welding. Girth seam rivet to rivet cracks, not more than 3 rivets can be repaired by welding if they are not within 6 inches of the longitudinal seam.

Longitudinal Lap cracks are cracks that run from rivet hole to rivet hole. The boiler is condemned immediately and no repairs are allowed due to the danger that lap cracks represent. These cracks could continue to spread between rivets until the boiler exploded. Lap cracks can occur behind the straps and cannot be seen, increasing the danger. Any steam leak around a riveted joint or any leak around a seam, welded or riveted is cause to shut down the boiler immediately and call for the Inspector.







Riveted boilers are also subject to a phenomenon known as "caustic embrittlement". When highly caustic boiler water works its way between riveted boiler plates that are highly stressed, the boiler metal will become brittle and will not flex with the stress placed upon it by the steam pressure. The result is a disastrous steam explosion that would wreck the plant and usually kill the Operator. This is the main reason why boilers are welded today.

Chapter 3 Questions

1. Why aren't boilers riveted today?
2. What is the limit in the thickness of plate in punching holes through the plate?
3. Which way does the girth seam run?
4. Which way does the longitudinal seam run?
5. Which seam is inherently stronger?
6. Which seam is built stronger because it is inherently weaker?
7. What is a lap joint?
8. What is a butt joint?
9. What is pitch in reference to rivets?
10. Which is the strongest riveted joint?
11. What is the factor of safety?
12. What is the average life expectancy of a boiler?
13. What is caustic embrittlement?
14. Why is caustic embrittlement dangerous?

Riveting the Girth Seam. Note how the sheets are bolted together and then every other one is riveted to keep the rivet holes aligned.

Chapter 4

BOILERS and STAYS

Boilers are classified in many different ways. They can be classified:

1. by intended use.....(heating or power boilers)

2. by what is inside the tubes.....(fire tube or water tube)

3. by firing arrangement.....(internally or externally fired)

4. by whether fixed or mobile ....(stationary, portable, locomotive, or marine)

5. by physical arrangement.....(horizontal or vertical)

6. by fuel.....(coal, oil, gas, wood, etc.)

The most common way to identify a boiler is by whether it has the products of combustion flowing through the tubes with the water surrounding the tubes (fire tube) or whether the water flows through the tubes and the products of combustion surround the tube (water tube). Using this definition, we will be studying the following boilers.

Fire Tube:

1. Horizontal Return Tubular (HRT)
2. Vertical Dry Top
3. Vertical Wet Top
4. Manning
5. Locomotive
6. Scotch Marine (wetback and dryback)

Water Tube:

1. Wickes Vertical Water Tube
2. Babcock and Wilcox Horizontal Drum (sinuous header)
3. Babcock and Wilcox Cross Drum (sinuous header)
4. Heine (box header)
5. Standard Stirling
6. Wickes A

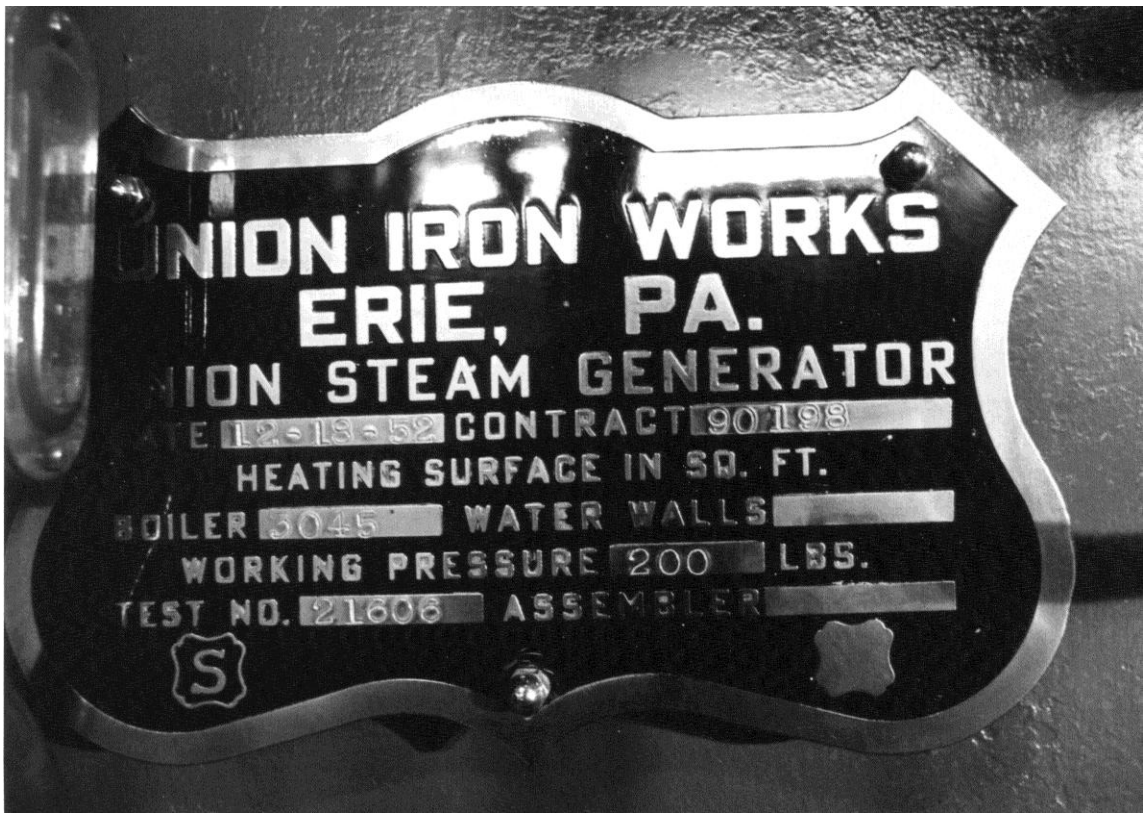
By internally fired we mean that the fire is surrounded on top, front, back, and sides by boiler steel. Only the bottom is open to allow air to enter and ash to be withdrawn (in the case of a solid fuel boiler such as coal). Using this definition, only the following boilers are internally fired:
1. Vertical Dry top
2. Vertical Wet Top
3. Manning
4. Locomotive
5. Scotch Marine

The Scotch Marine varies from this definition in that it has a tubular furnace that is only open to the outside at the front.

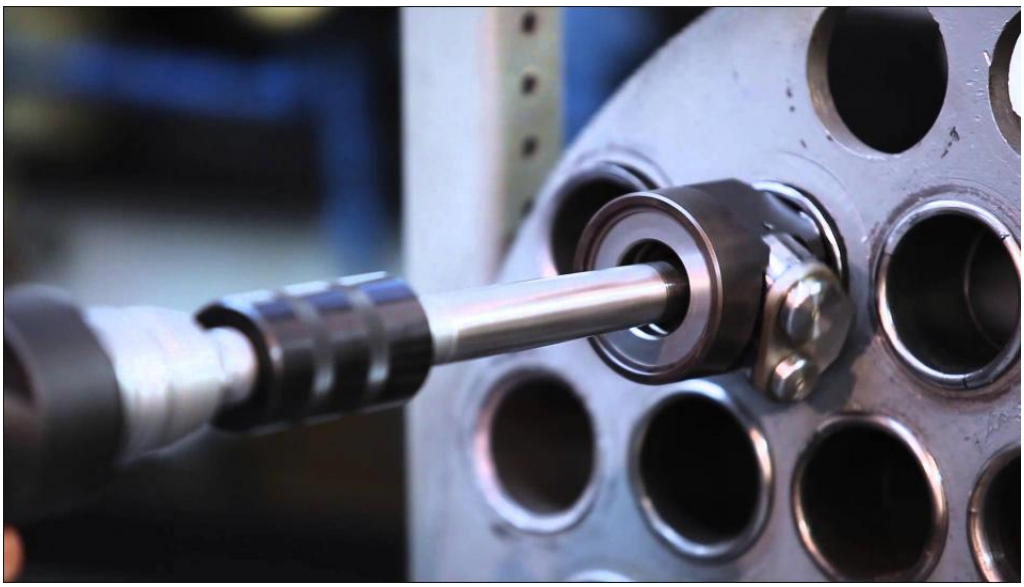
All other boilers that we will discuss are externally fired.

GENERAL MODERN BOILER DESIGN CHARACTERISTICS

1. ASME stands for the American Society of Mechanical Engineers. Before they established Boiler and Pressure Vessel Codes in 1914, boilers explosion due to manufacturing defects were all too common. Since these Codes have been established, the vast majority of boiler incidents have been caused by maintenance neglect or Operator error.



2. A mud drum is provided to allow sediment to be collected and discharged at the lowest and coolest spot in the boiler, and should have sufficient capacity to keep the sediment from backing up into the tubes.



3. In fire tube boilers, tubes are rolled, flared and beaded over to prevent their being burned off by the fire. The tube extends past the tube sheet. The tubes are expanded with a roller to grip the tube sheet. The ends of the tubes are beaten with a flaring tool to give a cone shape to the end of the tubes. The beading tool bends the flare over until it forms a tight bead around the tube sheet. Since the bead is now in direct contact with the tube sheet, the water in the boiler can cool the bead and prevent it from being burned off. After beading, the tube can extend beyond the tube sheet no less than 1/8 inch and no more than 1/4 inch. Holes in tube sheets are 1/32th of an inch bigger in diameter than the tube on the fire end, and 1/16th of an inch bigger in diameter than the tube on the other end.

Washing the boiler tubes before inspection

4. In water tube boilers, tubes are rolled and flared. The tube can project no less than 1/4 inch and no more than 3/4 inch before flaring. The flare is in the water of the boiler and does not need the extra protection of beading. Holes in the drum are 1/32 of an inch larger in diameter than the tube on both ends. Water tubes at the bottom of upper drums are beaded to allow drainage.

5. Manholes are provided to allow access to the drum for inspection and cleaning. They are either a minimum of 11" X 15" elliptical, 10" X 16" elliptical or 15" round. Round manholes have to be placed inside the boiler drum before the ends are welded on as the sealing lip on the manhole cover will not allow it to be removed after it is installed. The Code requires that gasket bearing surface on a manhole cannot be less than 11/16 of an inch. The gasket cannot be over 1/4 inch thick when compressed. The minimum handhole size is 2 3/4 inches X 3 1/2 inches, but larger sizes are recommended

6. The steam space should be large enough to allow the steam bubbles to escape the surface of the water without causing the water to surge over into the steam outlet.

7. All joints should be protected from direct fire impingement.

8. The combustion chamber should be large enough to allow complete combustion of the fuel before it comes in contact with the cooling surface of the boiler.

9. There should be a constant and thorough circulation of water throughout the boiler to maintain all parts at nearly the same temperature as possible.

10. It should be built strong enough to handle stress and strain without any part failing, but not with steel so thick that proper cooling of the boiler metal cannot occur.

11. The water should be divided into smaller areas so that the failure of one component will not cause the failure of the entire boiler. A water tube can burst without the comparable destruction caused by the shell of a fire tube boiler exploding. This means that a water tube boiler is inherently safer than a fire tube boiler.

12. The boiler should be easy to clean and repair.

13. The furnace should be designed so that the three "T"s of combustion; time, temperature, and turbulence can occur for complete burning of the fuel.

MINIMUM ACCESSORIES

The minimum accessories for a modern boiler are

1. Safety valve
2. Pressure gauge
3. Water column and gauge glass with high and low water whistle
4. Try cocks
5. Main steam valve
6. Stop, check, stop valves in feed water line
7. Feedwater regulator
8. Low water cut-out
9. Blowdown valves

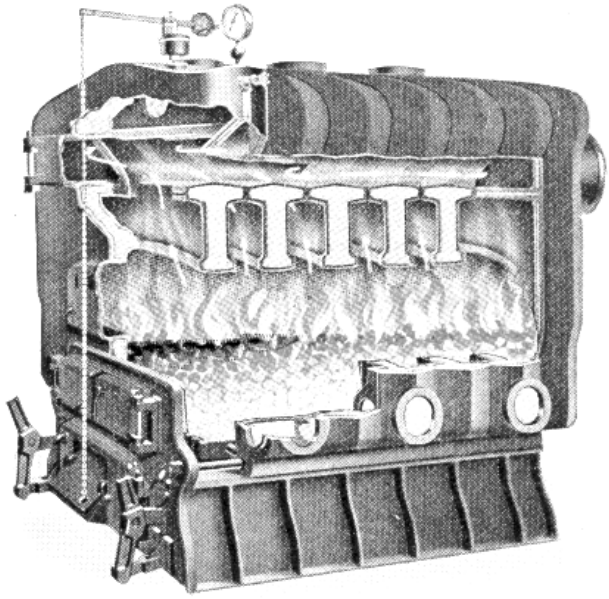
We will be discussing all of these accessories in detail in later chapters of the PDF.

BOILER HORSEPOWER

A boiler horsepower is defined as the ability of a boiler to evaporate 34.5 pounds of water from 212 degrees Fahrenheit to steam at 212 degrees Fahrenheit at atmospheric pressure. A boiler was rated at 10 square feet of heating surface for each horsepower developed by the steam engine. Advances in boiler design have made this rating obsolete but license examinations still refer to it.

MATERIALS USED TO CONSTRUCT BOILERS

Small low pressure heating boilers can be made from cast iron and are referred to as cast iron sectional boilers. These boilers are easy to construct due to the way that numerous sections of the boiler can be put together to build the size needed. "Push Nipples" are used as a water-tight way to connect the sections together with threaded steel rods on the corners running the length of the boiler holding the entire assembly together.

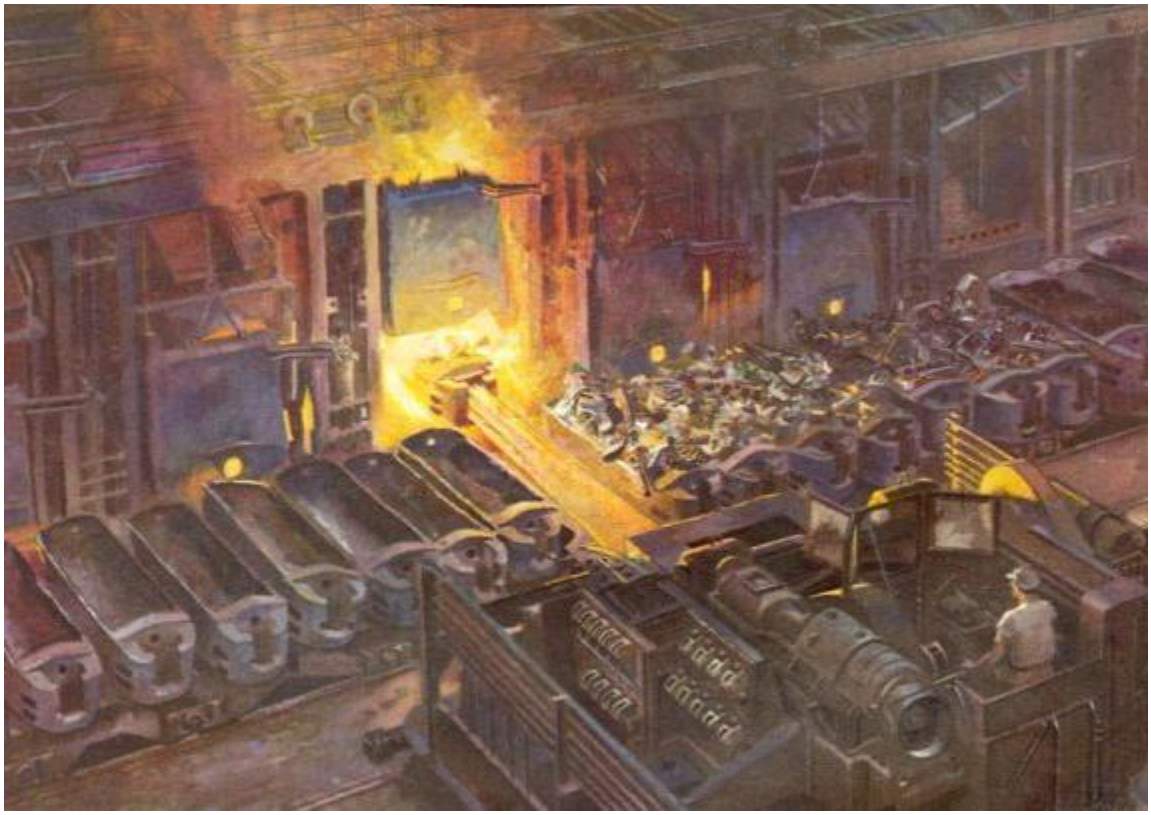


The problem with the cast iron sectional boiler is the sand casting method used to form the passageways in the cast iron. This method can create hollow spaces within the cast iron that cannot be seen. This weakens the boiler and can lead to explosion. Because of the low first cost of these boilers, they tend to be bought by building owners who do not know or care about proper maintenance. This can lead to scale buildup in the passageways of the boiler which then leads to meltdown or explosion.

Some parts of boilers are made of wrought iron. Wrought iron has more of a fibrous structure than steel due to the slag inclusions generated when melting the iron in the puddling furnace to remove carbon from the iron. Wrought iron is malleable while cast iron is brittle. Wrought iron can be used for tubes or headers.

Modern boilers are made from mild steel. Mild steel is pure iron with 1% or less carbon combined with it. Boiler plate usually has less than .25% carbon. If the carbon content gets too high, the steel gets brittle. Other elements found in small traces in mild steel consist of sulfur, phosphorous, manganese and silicon. Sulfur and phosphorous are definitely detrimental to boiler steel. Sulfur makes steel hot-short or brittle when hot. Phosphorous makes steel cold-short or brittle when cold. Manganese helps neutralize sulfur. Silicon makes steel harder.

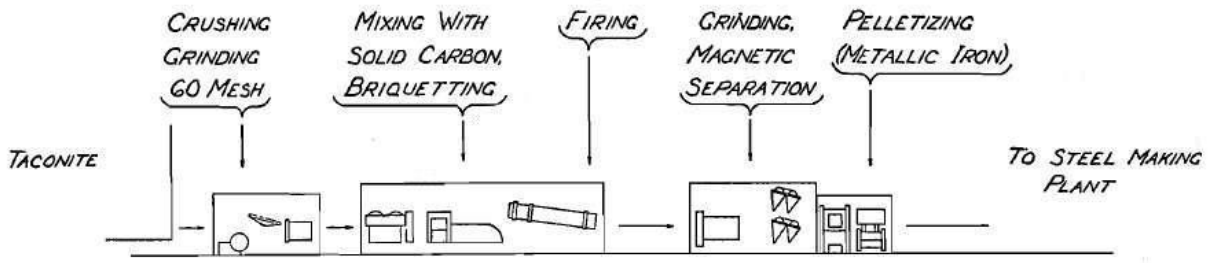
Mild steel is made by the open-hearth method. In the open-hearth method, the iron is melted in a gas fired furnace. The flame is directed to hit the roof of the furnace and then rebound off the reverberatory arch to hit the iron and melt it. By using refractory of an alkaline substance, the resulting chemical reactions are called the basic process. If the refractory were made from acidic material, then it would be the acid process. Steel for boilers is either of firebox or flange quality. Firebox steel has less detrimental trace elements than flange steel. Steel for boiler parts exposed to the fire or products of combustion must be firebox steel. Steel for the rest of the boiler may be either firebox or flange quality.



Most of the high grade iron ore used for steel making was mined in the Great Lakes area of Michigan, Wisconsin, and Minnesota. Lower grade taconite is now mined in Minnesota. Open pit mining is the most economical method of extracting the taconite.

Open Pit iron mine in Minnesota

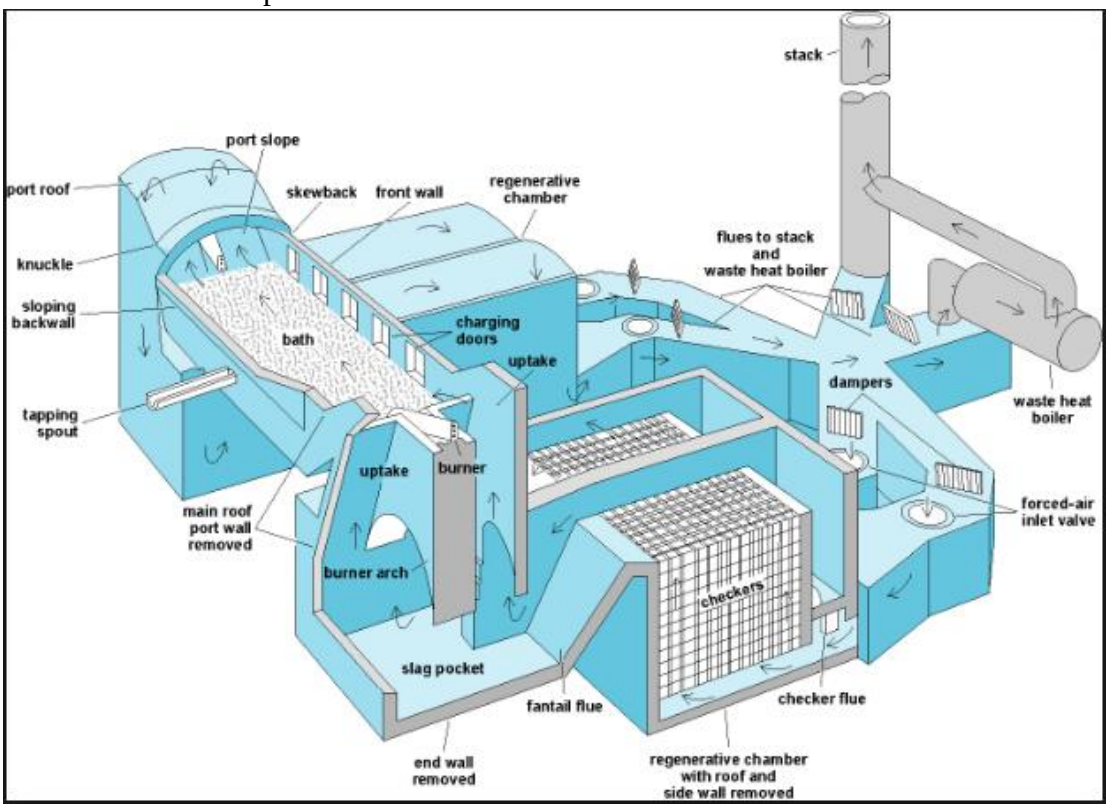
In the late 19th and early 20th centuries, available iron ore was of such high quality that taconite was considered an uneconomic waste product. After World War II, much of the high grade iron ore in the United States had been mined out, and taconite became a new source of iron. Taconite pellets are manufactured by a process known as "oxide pelletizing." To process taconite, the ore is ground into a fine powder, the magnetite is separated from the waste rock by strong magnets, the powdered iron concentrate is combined with a binder such as bentonite clay and limestone as a flux, and rolled into pellets about one centimeter in diameter containing approximately 65% iron. The pellets are fired at a very high temperature to harden and make them durable.

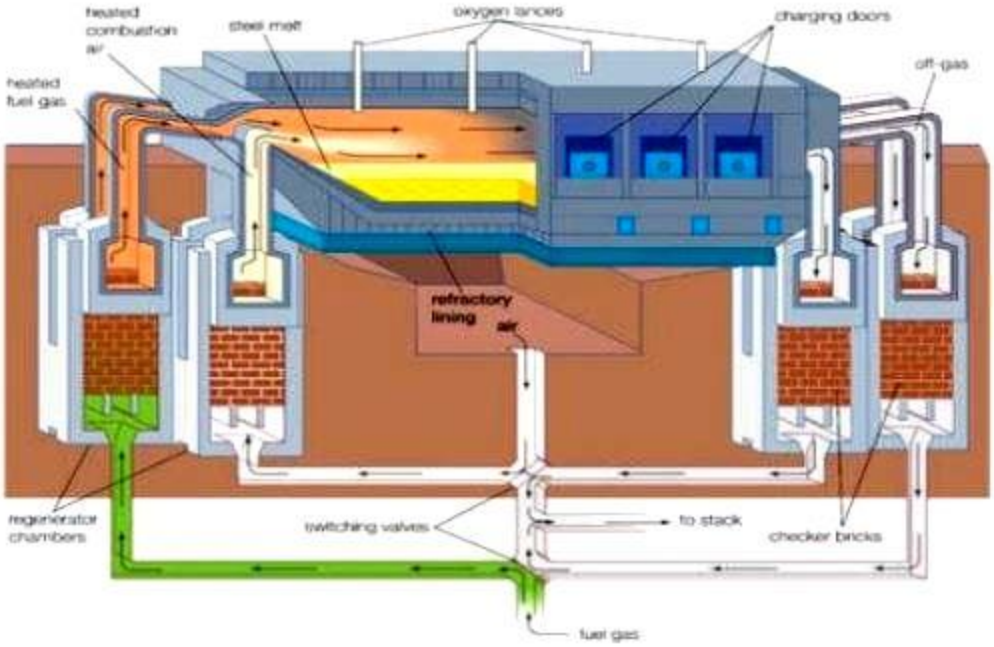


Taconite Processing

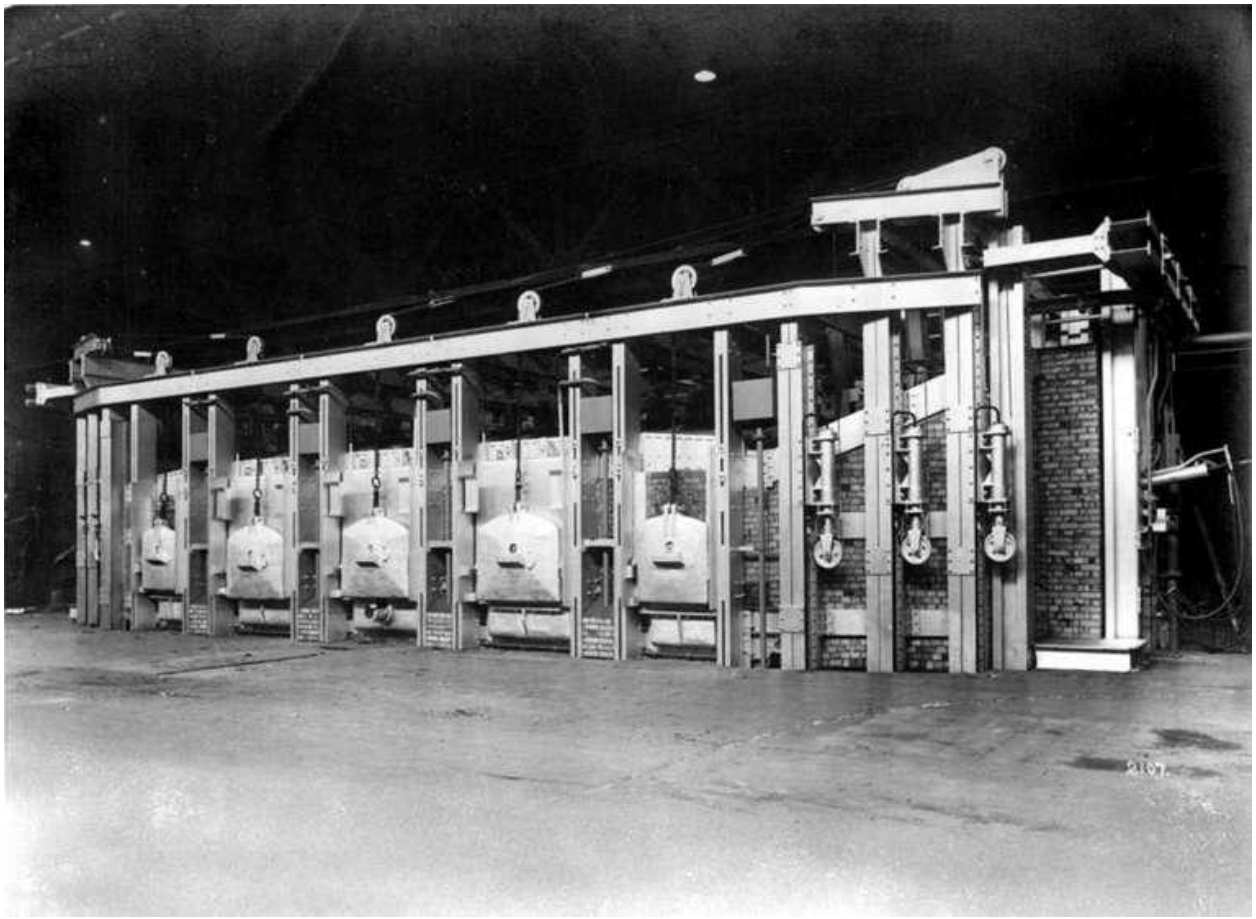
Taconite pellets with a dime for size comparison. On November 9, 1975, the S.S. Edmund Fitzgerald began loading 26,116 long tons of taconite pellets at Burlington Northern Railroad Dock No. 1 in Superior, WI.

Once the iron ore pellets are received by Great Lakes Freighter or railroad at the steel mill, they are fed into an open hearth furnace. Boiler steel is made by the open hearth process as opposed to the Bessemer blast furnace process.





Open Hearth Furnace. The fuel and air are burned over the pool of molten steel from one side and then the process is reversed and the fuel and air are burned from the other side.



Open Hearth Furnace Charging Doors

The steel starts in as "scrap" in the mill-yard. Scrap from anywhere in America; a broken casting, the size of a man's trunk, down to corroded pipe, or strips the thickness of your nail, salvaged in bales. The overhead crane gathers them all from arriving flat cars by a magnet as big as an ox cart wheel, and the pieces of steel leap to meet it with apparent joy, stick stoutly for a moment, and fall released into iron charge-boxes. By trainloads they pass out of the stockyard and into the mill, where the track runs directly in front of the furnace-doors. There the charging-machine dumps them quickly into the belly of the furnace. It does its work with a single iron finger, about ten feet long and nearly a foot thick, lifting the box by a cleat on the end, and poking it swiftly into the flaming door. Furnaces hold up to two hundred and fifty tons of scrap.

Charging machine loading scrap into the Open Hearth furnace

Charging-machine with trough of scrap steel

That is the first step in starting to make a "heat," which means cook a bellyful to the proper temperature for steel, ready to tap into a ladle for ingot-making. Next comes "making front-wall," which signifies that no self-respecting brick, clay, or any other substance, can stand a load of metal up to steel-heat without being temporarily relined right away for the next draft of flame. We do that relining by shoveling dolomite into the furnace. The official known as second-helper wields a giant spoon, about two inches larger than a dinner-plate and fifteen feet long, which a couple of third-helpers, fill with dolomite. By use of the spoon, he carefully spreads the protection over the front-wall.

The job on the open-hearth comes a bit later, consists in "making back-wall." Then all the men on the furnace and all the men on your neighbor's furnace form a dolomite line, and marching in file to the open door, fling their shovelfuls across the flaming void to the back-wall. It's not a beginner's job. You must swing your shovel through a wide arc, to give it "wing," and the stuff must hop off just behind the furnace-door and rise high enough to top the scrap between, and land high. What lends life to the sport is the fact that everybody's in it—it's the team play of the open-hearth, like a barn-raising in Amish country.

Another thing is the heat. The mouth of the furnace gapes wide, and you must hug close in order to get the dolomite across. Every man has deeply smoked glasses on his nose when he faces the furnace. He's got to stare down her throat, to watch where the dolomite lands. It's up to him to place his stuff—the line isn't marching through the heat to warm its hands. Here's a tip I didn't "savvy" on my first back-wall. Throw your left arm high at the end of your arc, and in front of your face; it will cut the heat an instant, and allow you to see if you have "placed" without flinching. It's really not brawn,—making back-wall,—but a nimble swing and a good eye, and the grit of not minding the heat.

Shovelling in the dolemite

When it's time for a test, the first-helper will take a spoon about the size of your hand and scoop up some of the soup. But not to taste. He pours it into a mold, and when the little ingot is cool, breaks it with a sledge. Everyone on the furnace, barring myself, looks at the broken metal and gives a wise smile. They know by the grain if she has too much carbon or needs more, or is ready to tap, or isn't. With too much carbon, she'll need a "jigger," which is a few more tons of hot metal, to thin her out.

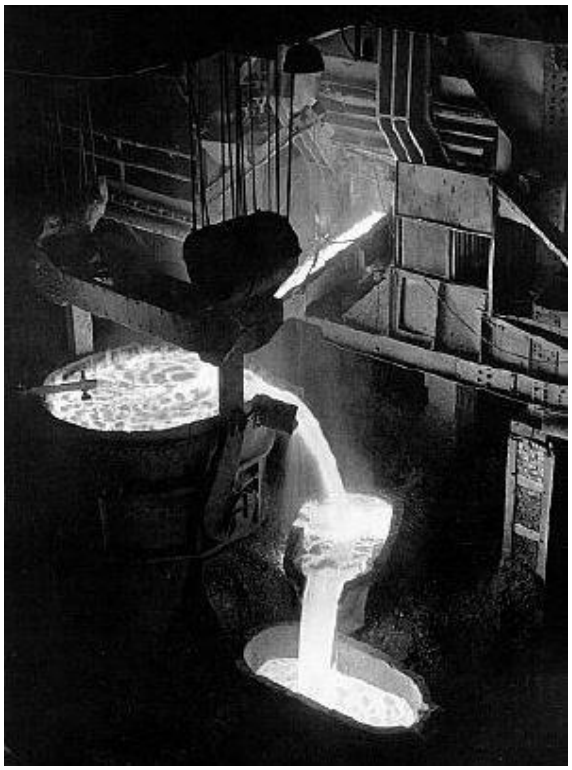
Sampling the steel

That's about the whole game -- up to tap-time. It takes, on an average, eighteen hours, and your shift may be anything from ten to twenty-four. Of course, there are details, like shoveling in fluorspar to thin out the slag. Be sure you clear the breast of the furnace, with your shovelful, when you put that into her. Fluorspar eats the dolomite like mice eat cheese. by Charles Walker

Fluorspar is now essential in the production of:
01 Steel
Fluorspar is an excellent flux - it makes steel smelting more energy efficient

Fluorspar ore

The limestone slag, immediately after the heat is melted, lies like a blanket upon the bath and to insure proper oxidizing conditions it is necessary to thin up the slag, and render it more fluid so that the metallic contents of the bath will come into more intimate contact with the oxidizing slag. It is the universal practice in this country to use fluorspar for this purpose. Fluorspar acts as a neutral reagent and does not affect the basicity of the slag. The increased fluidity not only allows for quicker elimination of impurities in the metal but allows the transference of heat from the fuel to the bath of metal in much quicker time.



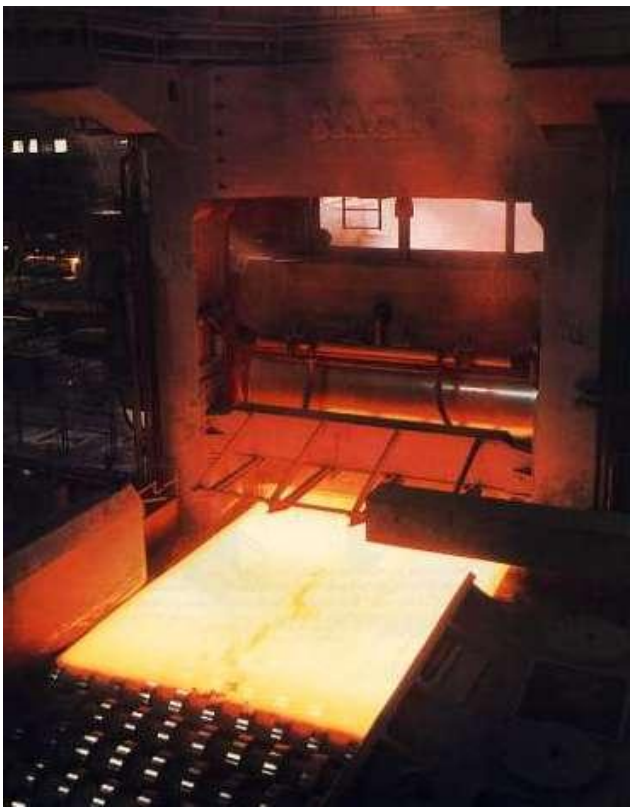
Skimming off the slag

In early years it was the general practice to add fluorspar just before the furnace was ready for tapping. It has become the more general practice to add the fluorspar in the early stages of the working of the heat, not only to allow the slag time enough to function properly with regard to impurities in the metal, but to eliminate sulphur at higher temperature and to allow the furnaceman more opportunity to quickly raise the temperature of the bath in case it is necessary to tap the steel a little early.

At intervals the first-helper tilts the whole furnace forward, and she runs out at the doors, which is to drain off the slag that floats on top of the brew.

But after much weariness it's tap-time and the "big boss" comes to supervise.

Tapping the Furnace



The steel is then run through a rolling mill to produce boiler plate.

Boiler Plate awaiting shipment

Boiler plate at the boiler shop

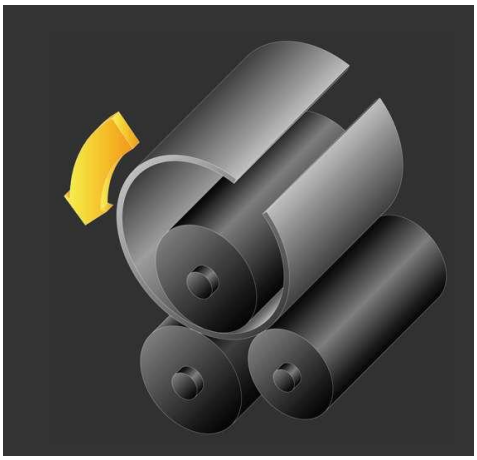
QUALITIES OF GOOD BOILER STEEL

Ductility	A ability to endure elongation without fracture or rupture	Degree of elongation of specimen in tension test	Stretching of staybolts or boilerplate or boiler tubes in tension
Malleability	Ability to endure change of shape by hammering, Bending, or rolling	Behavior of specimen in bending test	Flow of rivet material under blows of hammer or pressure of riveting machine
Toughness	Ability to endure continued torture by twisting and bending - absence of brittleness	Behavior of specimen in torsion test	Resistance of boiler plate to an alternating flexure in riveted seems
Resilience	Ability to add absorb kinetic energy without permanent deformation	Modulus of resilience as determined by tension test	Action of steel spring under but tension or compression
Homogeneity	Continuity and uniformity in the grain or fiber of the material	Appearance of fractured surfaces of broken specimen	Condition of a soft steel rivet after being driven under 80 tons pressure while at a reddish white heat
Tenacity	Ability to resist a pulling stress	Ultimate tensile strength as determined by tension test	Resistance of through stays
Elasticity	Capacity for resuming normal shape after deformation	Extent of deformation from which specimen will completely recover	Action of bourdon tube in a pressure gauge
Hardness	Ability to resist erosion or wear	Behavior of specimen in abrasion test, scratch test, or ball test	Imperviousness of good firebox steel to the cutting action of cinders

Desirable characteristics of boiler steel are presented to the left. Tensile strength is tested by pulling on the steel and measuring when it will break after stretching.

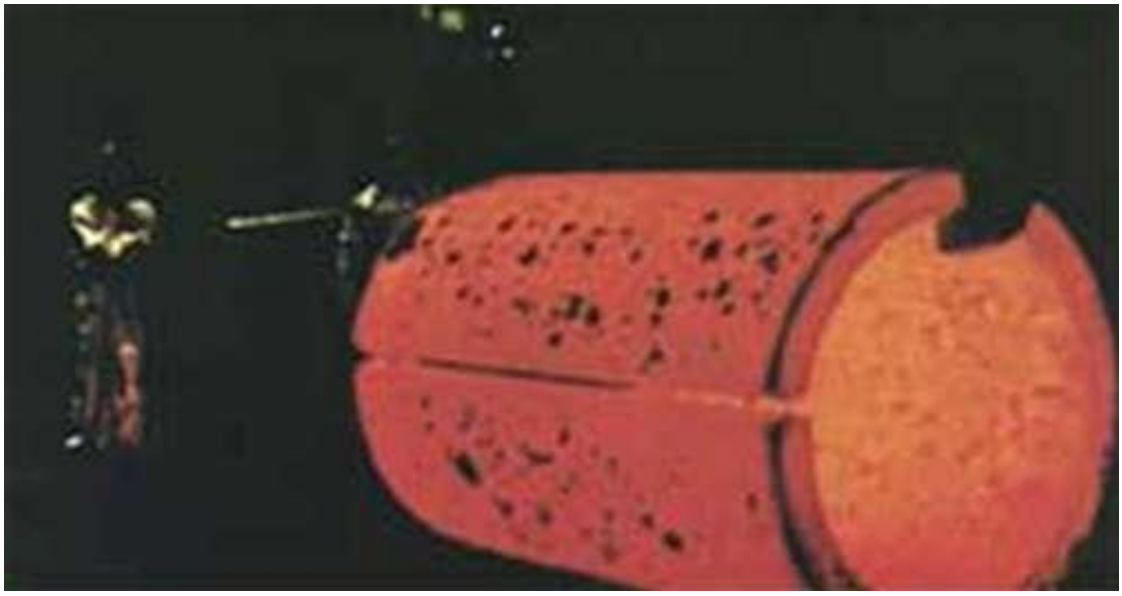
The boiler plate is heated and moved into position for rolling into a cylinder

The steel is started rolling into a cylinder



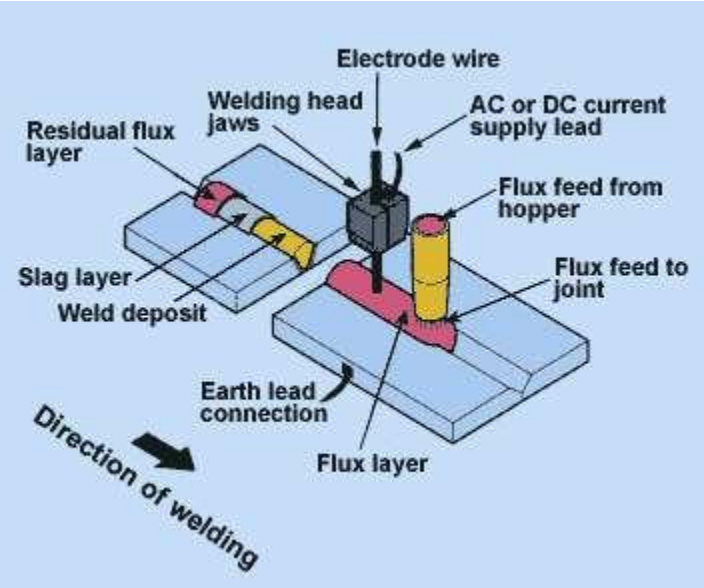
This diagram shows the principle of rolling

The cylinder has almost completed rolling



The cylinder is being moved in preparation for submerged –arc welding the seam

In submerged arc welding a mineral weld flux layer protects the weld area from the influence of the surrounding atmosphere. The arc burns in a cavity filled with ionized gases and vapors where the droplets from the continuously-fed wire electrode are transferred into the weld pool. Unused flux can be extracted from behind the welding head and subsequently recycled.



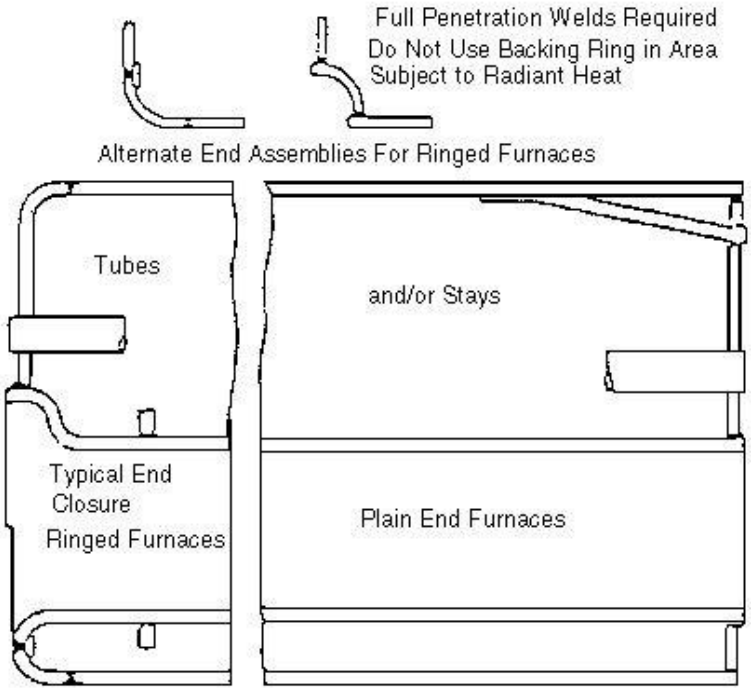
Cylinder ready to be welded by the submerged arc welder

The main components of a submerged arc welding unit are: the wire electrode reel, the wire feed motor equipped with grooved wire feed rolls which are suitable for the wire diameters, a wire straigthener as well as a torch head for current transmission. Flux supply is carried out via a hose from the flux container to the feeding hopper which is mounted on the torch head. Depending on the degree of automation it is possible to install a flux excess pickup behind the torch. Submerged arc welding can be operated using either an A.C. power source or a D.C. power source where the electrode is normally connected to the positive terminal. Welding advance is provided by the welding machine or by workpiece movement.

Smooth welding bead produced by submerged arc welding

The most common boiler in the United States today is some version of the Scotch boiler, either the dryback or the wetback.

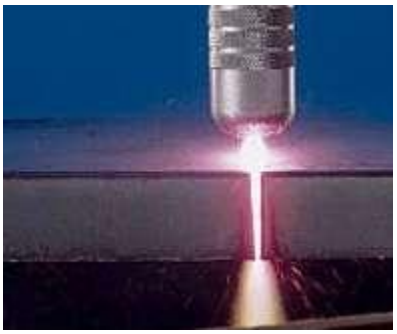
In the dryback Scotch boiler, after the shell is welded, a front and rear tube sheet are fitted, welded, and the areas without the tubes are reinforced. Notice the holes at the top of the tube sheet where the reinforcing rods or stays will be welded.

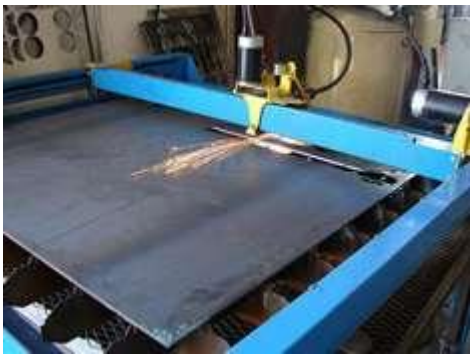


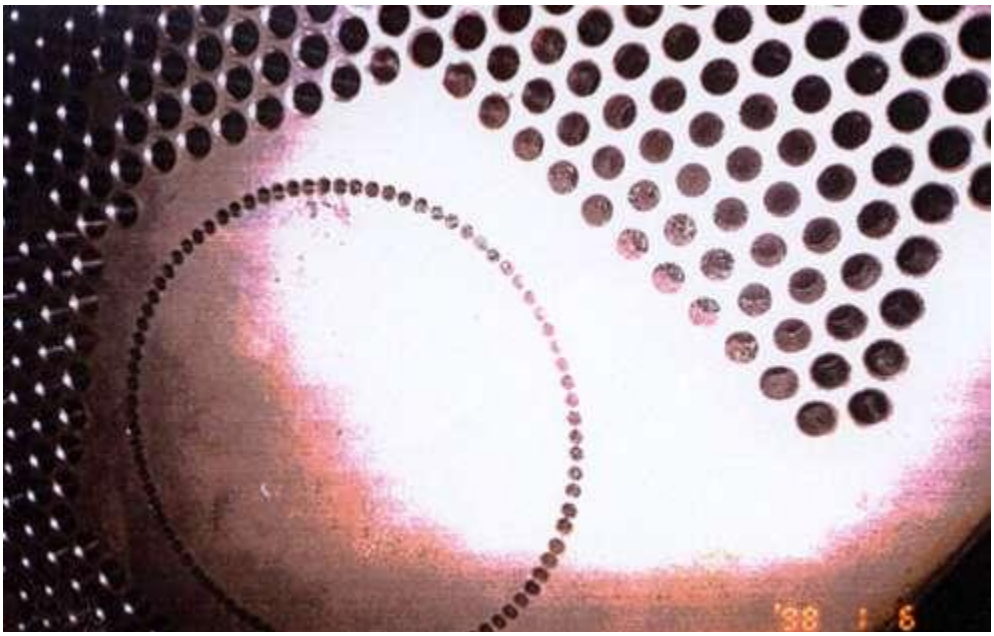
Modern welded diagonal stay

Longitudinal seam in furnace double butt-welded and thermally stress-relieved. For repair, the final joint to each bead may be stress-relieved by peening. The furnace may be welded into a riveted boiler by using adaptable end closures. Ringed furnaces shall be thermally stress-relieved after longitudinal seam and rings have been applied.

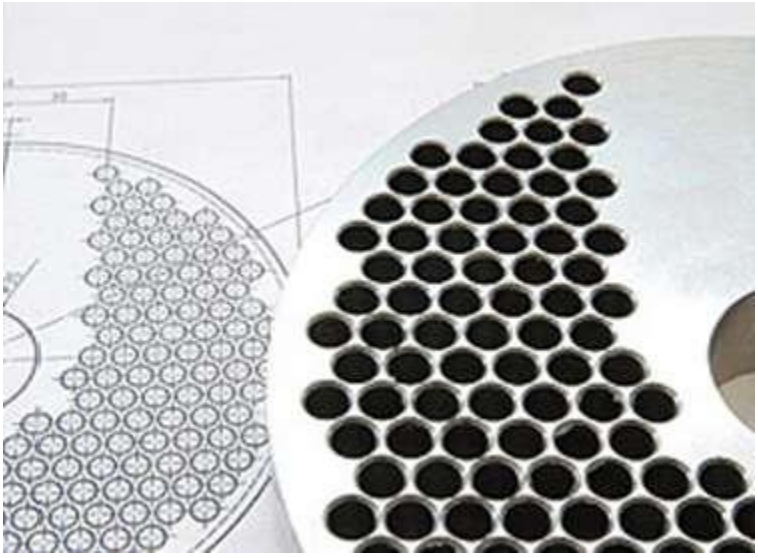
The end plates are cut out with a plasma torch. The tube holes are drilled or plasma cut smaller than the final size. The holes are then reamed to the final size and beveled or counterbored for the tubes to be expanded into.







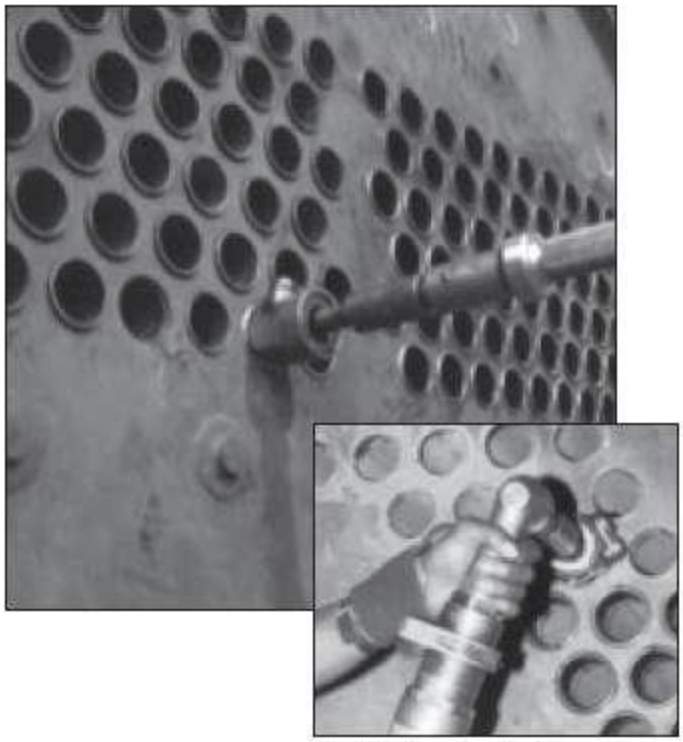
Drilling holes small holes to form a large circle before cutting out the furnace hole



Computer Aided Design Drawing to finished tubesheet

Heating and rolling in the corrugations of a Morison Furnace

Installing a Morison furnace into the boiler.

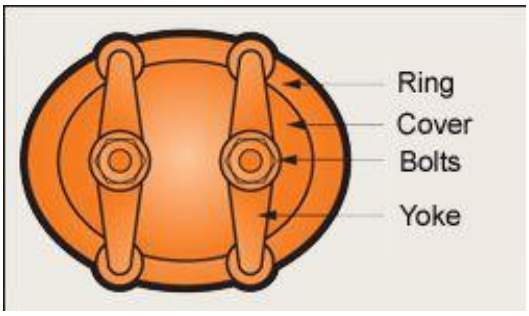


Combination Beading Expander in use with 909-Right-Angle Pneumatic Tube Roller

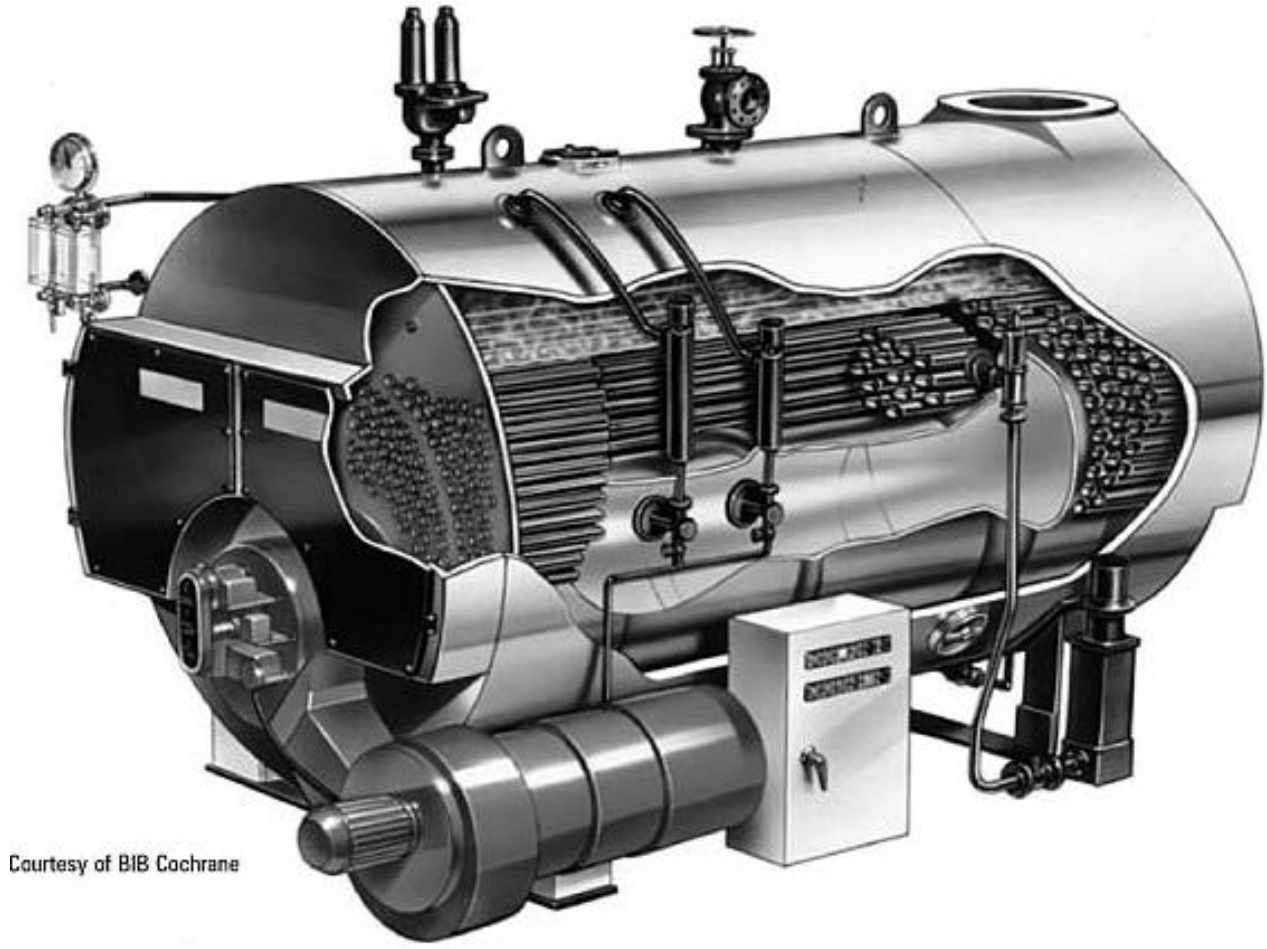
Fire Tubes can be rolled Flared and Beaded in one operation

Wilson Combination Beading Expander

The **Wilson Combination Beading Expander** *is one of our smartest tools!* Rather than expand a tube, than manually bead it, and then re-roll it with a straight roll expander, the patented **Combination Beading Expander (CBE)** from Thomas C. Wilson does all three jobs in one seamless process.



The oval hole for the manhole is cut into the top and a special flange is welded-in to house the manhole plate.



Various holes are cut into the boiler shell for safety valves, main steam outlet, water column, feedwater inlet, vent, pressure gauge, high pressure cut-out, and bottom blowdown.

After the welding is completed, insulation is added over the shell

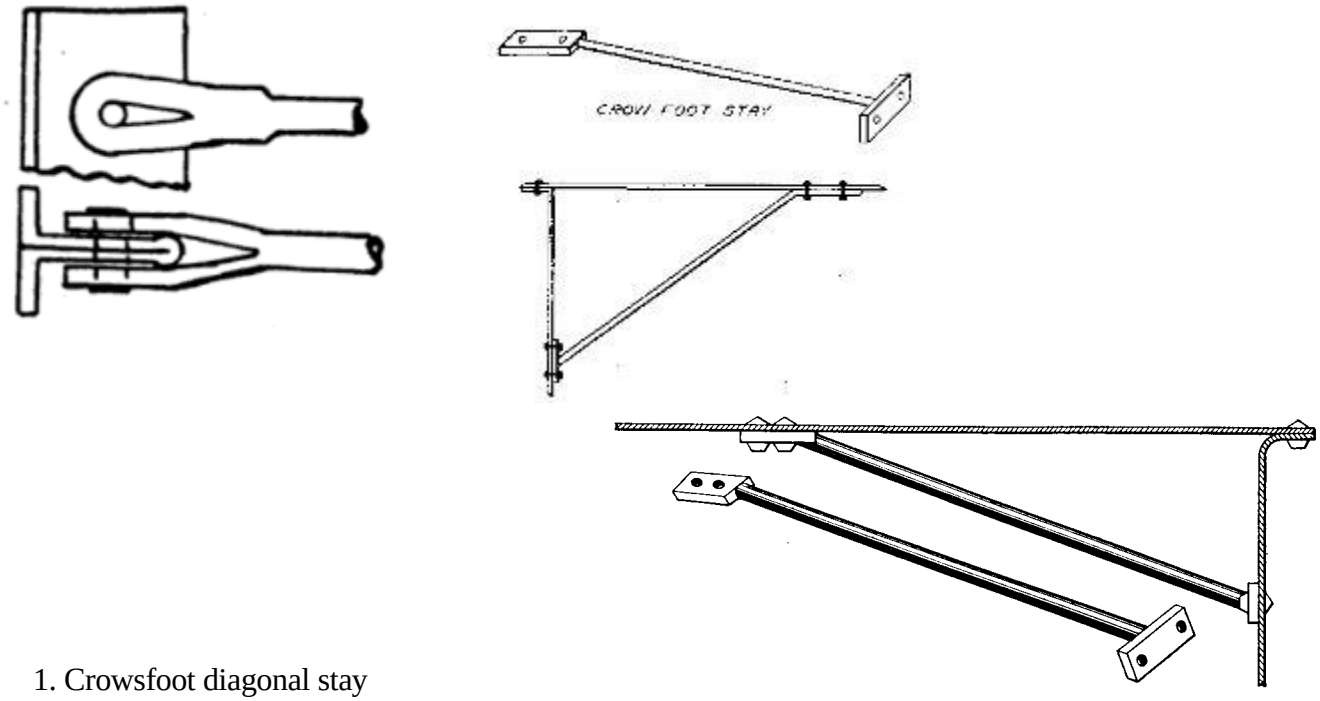
The insulation is then covered with sheetmetal

The boiler then has the appurtances and gas train installed and then the boiler is painted.

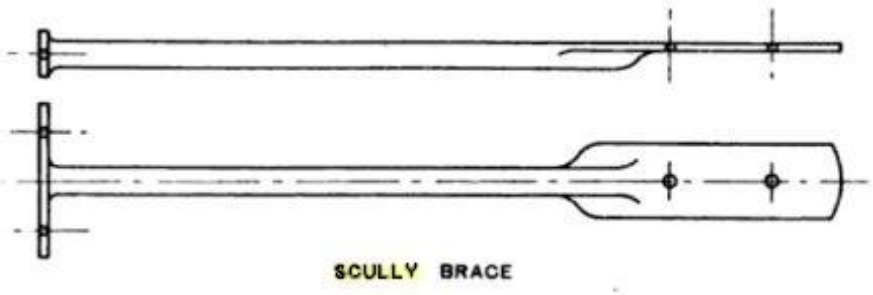
After the boiler has been inspected, hydrostatically tested, and test fired, it passes inspection and can be shipped by rail, boat, or truck. The packaged boiler must receive factory tests to check the construction, controls, and operation of the unit. All tests may be witnessed by the purchaser, if desired.

STAYS

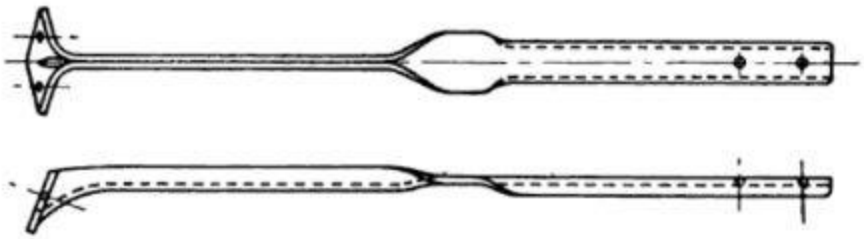
In order to hold the steel sheets of a shell type boiler together, various types of stays are used. A stay is a steel rod or girder that is in tension between two plates of steel. It holds the plates of the shell in place so that the sheets will not rip apart from the pressure inside the boiler. Through stays are inherently stronger than diagonal stays because the resist the pull at a 90 degree angle to the stress. Staybolts prevent the furnaces from bulging inward due to the pressure inside the boiler. The various types of stays are:



1. Crowsfoot diagonal stay

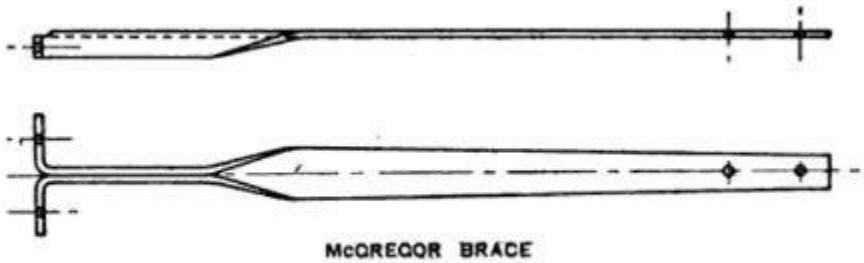


2. Scully diagonal stay. The Scully brace or stay is made from one piece of soft steel pressed to shape in a forging machine, no welds being allowed.



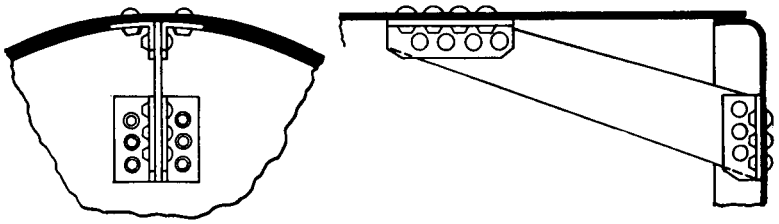
HUSTON BRACE

3. Huston Stay. The Huston brace is made of folded weldless steel plate. At its head end it is well reinforced by wide fillets and at its shell end by raised ribs along the sides. The thickness of metal from which this brace is made ranges from 3/8 in. to 1/2 in., depending upon the pressure in the boiler in which it is used. The lengths range from 24 ins. to 78 ins. inclusive by increments of 6 ins.

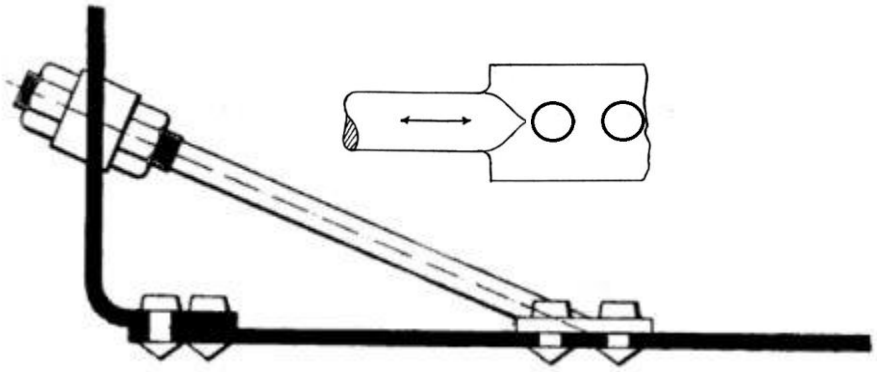


McGREGOR BRACE

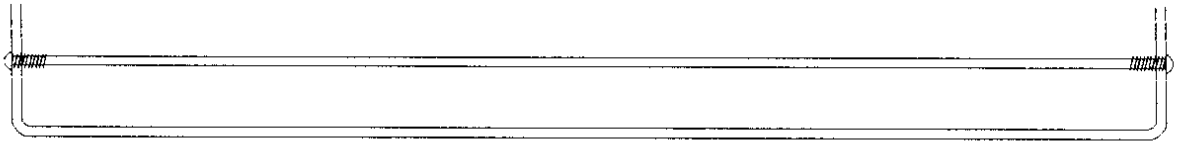
4. The McGregor brace is also made of folded metal but differs from the preceding one in the formation of its head. The latter is split and bent to a T-shape. Weldless material, varying in thickness from 3/8 to 1/2 in., is used throughout.



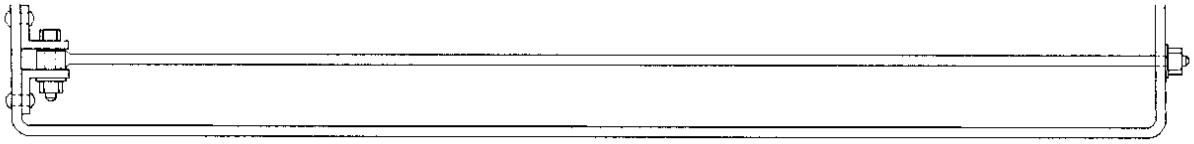
5. A Gusset stay is a triangular plate having a flange turned on two sides, which is used as a bracket-stay in the corners of a steam-boiler.



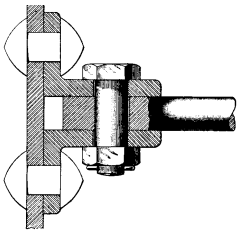
6. Palm stay



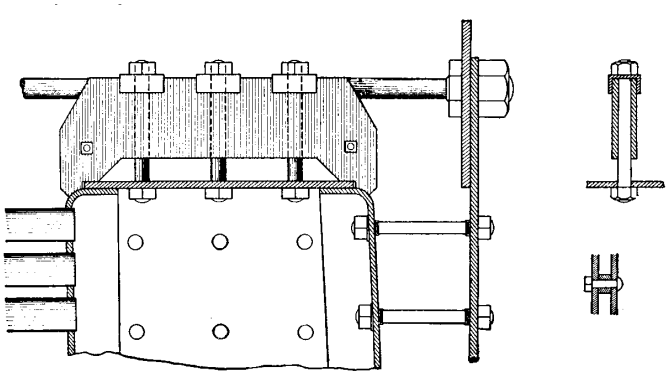
7. through stay



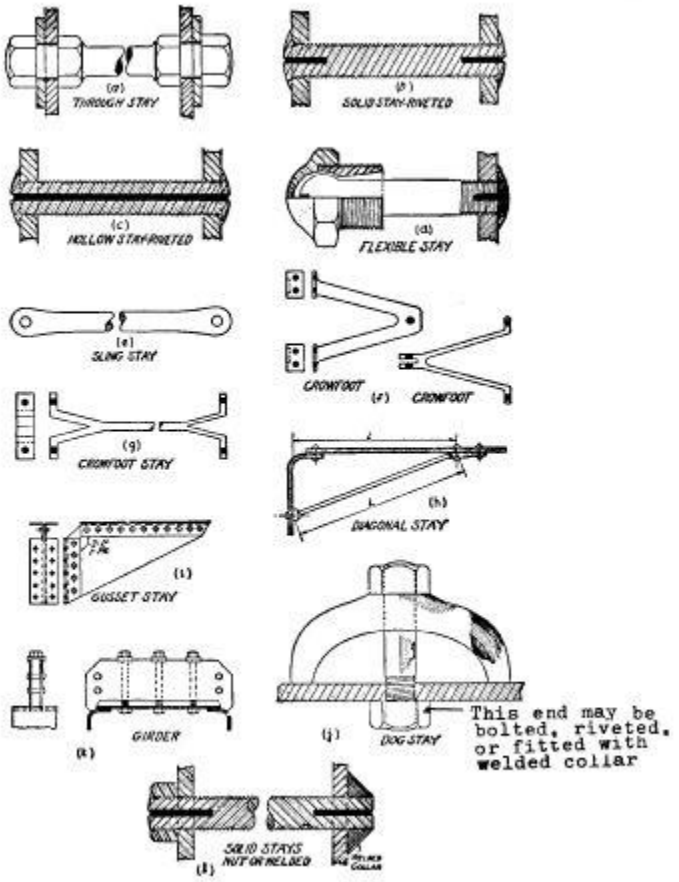
Through-to-head stay detail

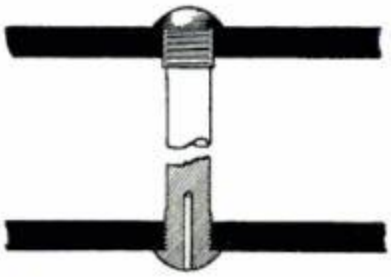


8. Through-to-head stay

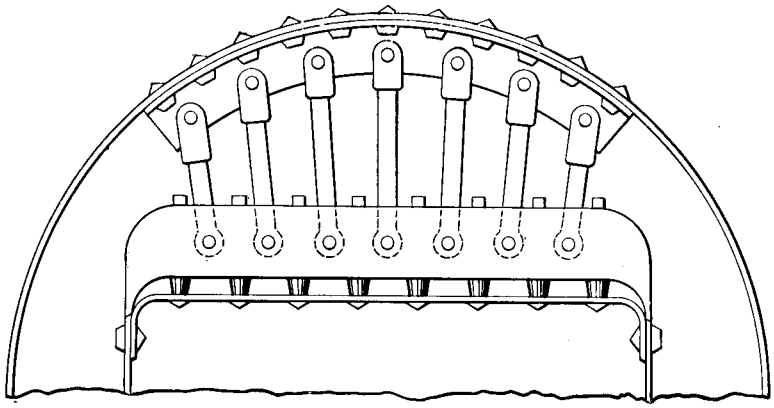


9. Girder stay

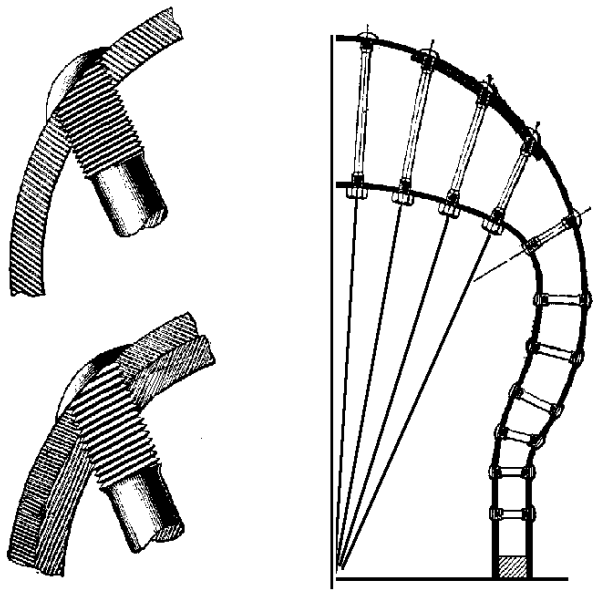




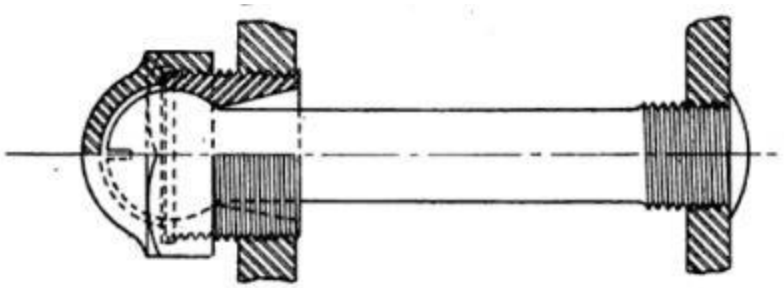
10. Tell-tale stay



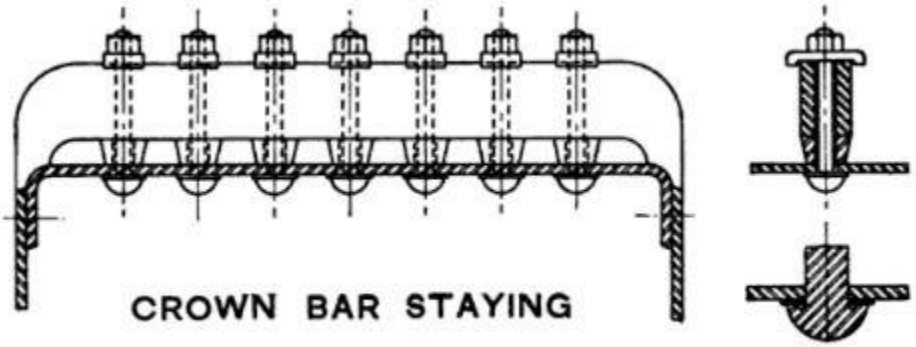
11. Sling stays

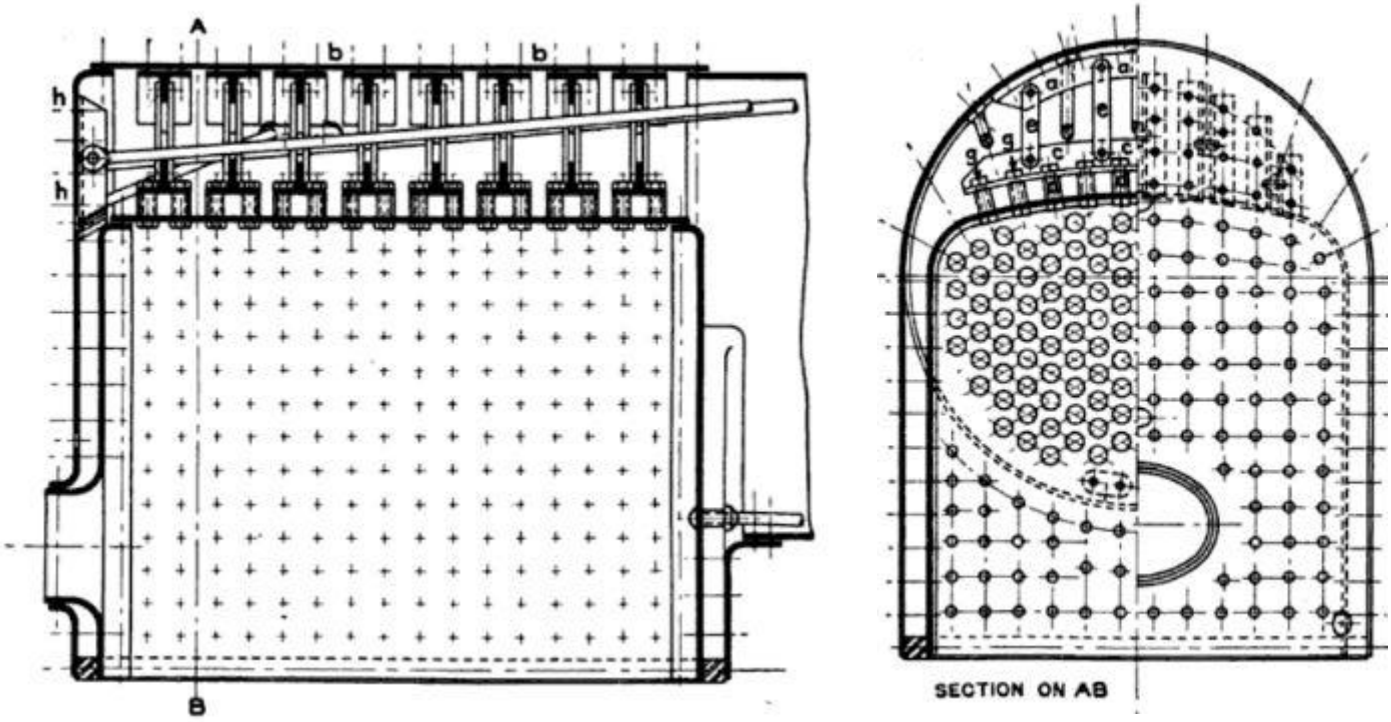


12. Radial stays

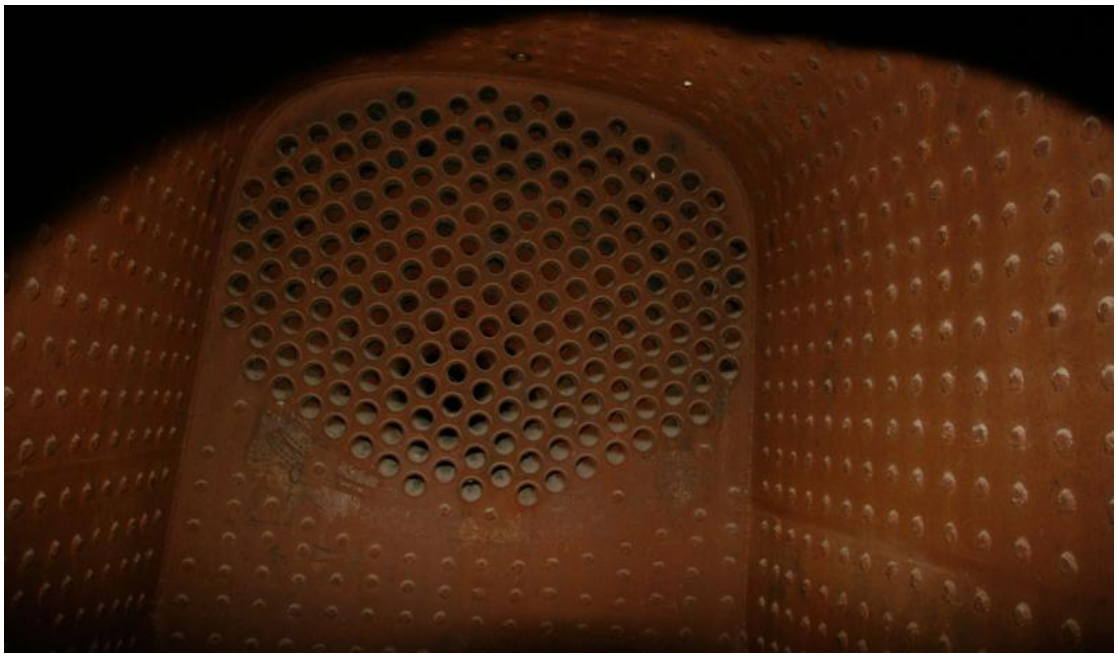


13. Flexible or "Tate" staybolt

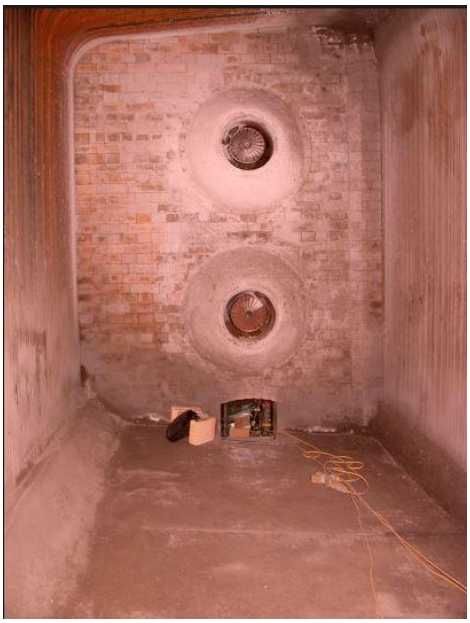




BOILER FURNACES



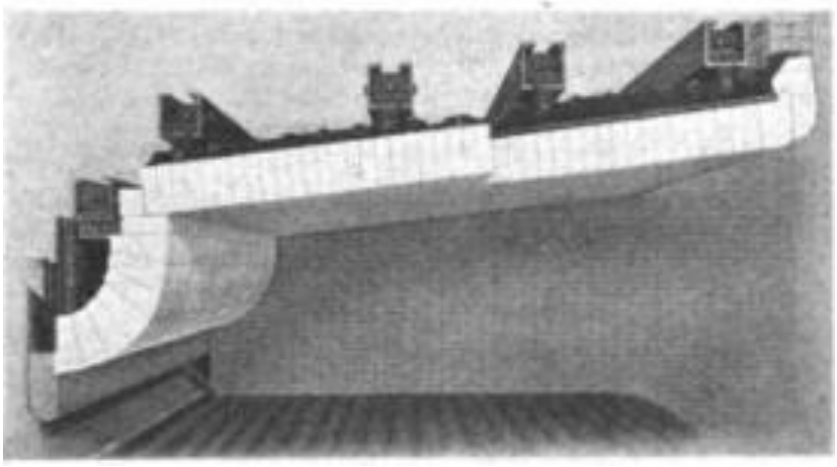
The furnace of an internally fired boiler is made from sheets of steel that enclose the fire on all sides except where the fuel is inserted and the ashes withdrawn.



The furnace of an externally fired boiler is usually lined with refractory to contain the heat of the fire within the furnace. Refractory is also used to maintain a stable flame on some types of oil fired burners. Refractory can also protect tubes from the erosive effects of direct flame impingement. Without refractory and insulation, the steel casings that surround the outside of the furnace would soon rust through. Refractory is a general term that refers to many types of materials and shapes.

Fireclay is a mixture of clay containing alumina and silica. The fireclay can be molded into firebricks that are laid like common brick inside the furnace with a thin mortar connecting the bricks. Expansion is taken care of by spaces at the ends of the walls. These refractory materials can withstand temperatures of around 2200 degrees Fahrenheit.

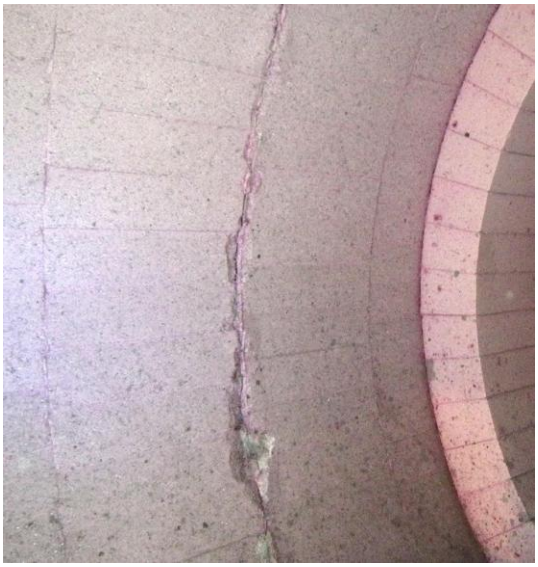
Refractory can also be made of kaolin, a fine grained clay with 45% alumina that can withstand a temperature of 3200 degrees Fahrenheit. Diaspore with an 80% alumina mixture can withstand 3300 degrees Fahrenheit. Silicon carbide, which is a compound of silicon and carbon, can withstand a temperature of 3100 degrees and because of its abrasion and slag resistance, is used around the clinker line of coal stokers. Chromium-clay cements are used as plastic refractory, withstanding temperatures of 3600 degrees Fahrenheit. Ceramic refractories can be used at temperatures up to 3200 degrees Fahrenheit.



Refractory is used provide a hot surface to distill gasses from green (unburned) coal that has been freshly introduced into the furnace, known as an ignition arch.

Important points to remember about refractories are:

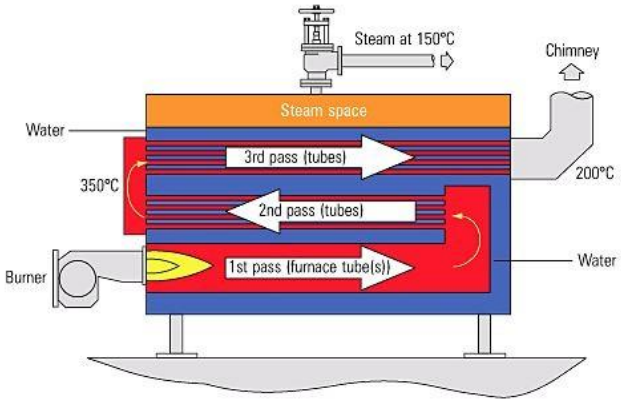
1. The refractory must not expand much at high temperatures or else the wall will have too much stress on it and cracks will develop.



2. "Spalling" refers to the fracture and breaking away of the refractory due to the temperature changes in the furnace on the individual brick. Prolonged exposure to the heat of the fire tends to vitrify the ends of the brick, turning the ends into a brittle glass-like substance that then produces a crack across the width of the brick. Cracks can also occur across the length of the brick, or else chunks of the brick will chip off, leaving a small crater.

3. Molten ash in the form of slag can gather on the refractory and enter the pores of the firebrick, fusing with it. The slag will then break off part of the brickwork, either by the weight of the clinker that is formed, or by the action of the Operator in trying to remove the clinker. A dense firebrick with a shiny surface will retard the formation of clinkers in the furnace wall.

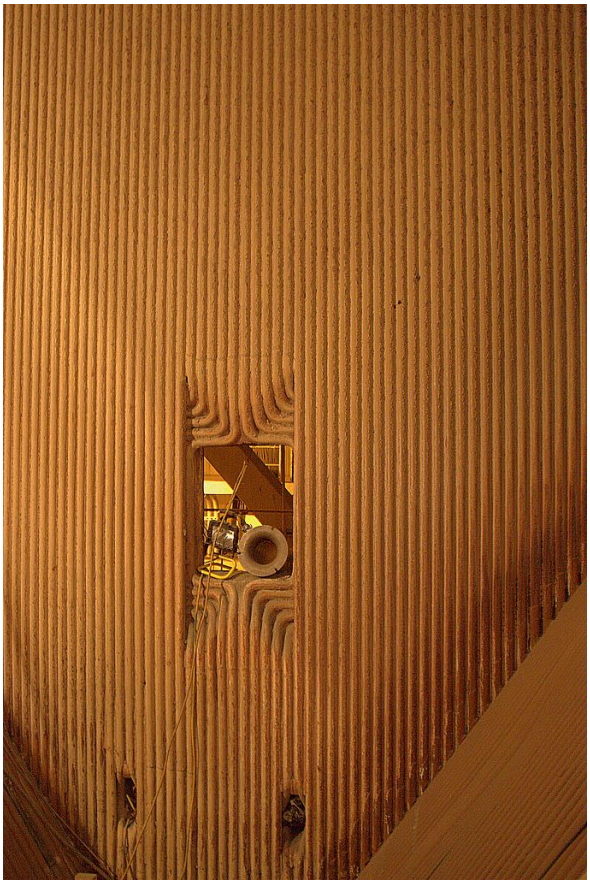
4. Plastic refractory can be molded to fit shapes that firebrick cannot. The word plastic has a general definition of being moldable. Fireclay that is capable of being worked before the fire has hardened it is plastic. This has nothing to do with the polymers associated with the modern usage of the word plastic, other than the fact that the polymers are also moldable.



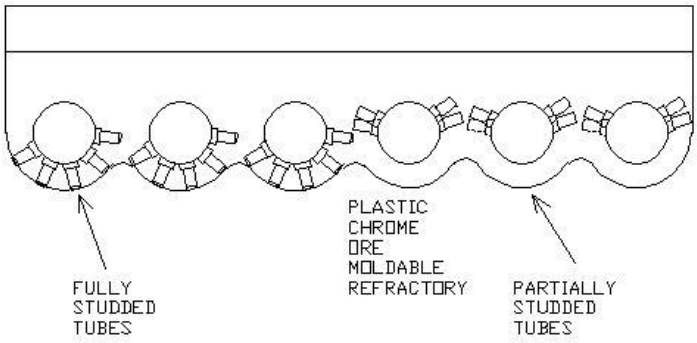
Economic boiler (three-pass, wet back)

Furnaces of boilers are divided into gas passes that force the products of combustion or flue gas to travel a longer path before they are allowed to leave the furnace. This longer path allows more heat to be absorbed by the boiler and more efficient use of the fuel being burned. To keep the flue gas velocity constant throughout the furnace, the passages for the flue gas are made progressively smaller as the flue gas travels toward the chimney. The flue gas contracts as it cools, lessening the volume of the gas in each pass. In a three gas pass boiler, the 3rd gas pass is smaller than the second gas pass, which is smaller than the first.

WATERWALLS



In order to extend the life of refractory in a water tube boiler, water tubes were added to line the furnace. The water in the tubes carried away the excess heat of the furnace, cooling the refractory. The early use of tubes to cool refractory is known as water cooled walls rather than waterwalls due to the 6 to 10 inch spacing between tubes. It was soon discovered that the waterwalls could generate more steam per square foot than the boiler itself. This led to more and more water tubes being placed in the furnace until all sides of the furnace consisted of waterwalls. Large utility boilers of today consist of waterwalls and a steam and water drum at the top to collect the steam. Strips of steel are welded to each side of the tube the length of the furnace to extend the heat gathering surface of the tube. This also helps seal the furnace. Insulation and sheet metal encase the waterwalls on the outside of the furnace. Some waterwalls have studs welded to the outside of the tube to increase heating surface, with plastic refractory packed between the tubes.



Important facts to remember about waterwalls are:

1. In order to line the furnace with water tubes, the tubes are rolled or welded into headers at the top and bottom of the furnace. The distance between the tubes in the header is known as the ligament. If the tubes are spaced close together, the ligament becomes weak from having so many closely spaced holes in it. To gain more distance between the ligament, and therefore more strength for the header, the tubes are either bifurcated or trifurcated. Bifurcating a tube means to weld each end of the tube to a Y shaped fitting that allows two tubes to be fed from one opening in the header. Trifurcating, which would resemble a three pronged pitchfork, allows three tubes to be fed from one opening in the header.

2. Waterwalls are never blown down when the boiler is operating. It upsets the natural circulation of the water. Water rises in the tubes next to the furnace due to the heat of the fire. Lack of proper water circulation due to blowing down will cause the tubes to overheat. Water falls in recirculating tubes or downcomers that are outside of the furnace.

Waterwall supports (Courtesy Foster Wheeler)

Waterwall Burner Throats
(Courtesy Vallourec)

Questions Chapter 4

1. Name 6 ways to classify boilers
2. How can you tell if a boiler is internally or externally fired
3. What is the difference between a fire tube and a water tube boiler?
4. What does ASME stand for?
5. What does "rolled, flared, and beaded" mean?
6. Why are the tubes in fire tube boilers beaded?
7. What are the minimum sizes for manholes?
8. What are the minimum sizes for handholes?
9. What are the minimum accessories needed for the modern boiler?
10. What is the problem with cast iron sectional boilers?
11. What does phosphorous do to steel?
12. What does sulfur do to steel?
13. How much carbon is in steel used for boilers?
14. What is the difference between firebox quality steel and flange quality steel?
15. Which is stronger, a through stay or a diagonal stay?
16. From what two ingredients is most refractory made?
17. What type of refractory is used around the clinker line?
18. What is a clinker?
19. Why were waterwalls first developed?
20. What is the tube ligament?
21. Why are waterwall tubes bifurcated or trifurcated?
22. Why aren't waterwalls blown down when the boiler is operating?

Bifurcated Waterwall

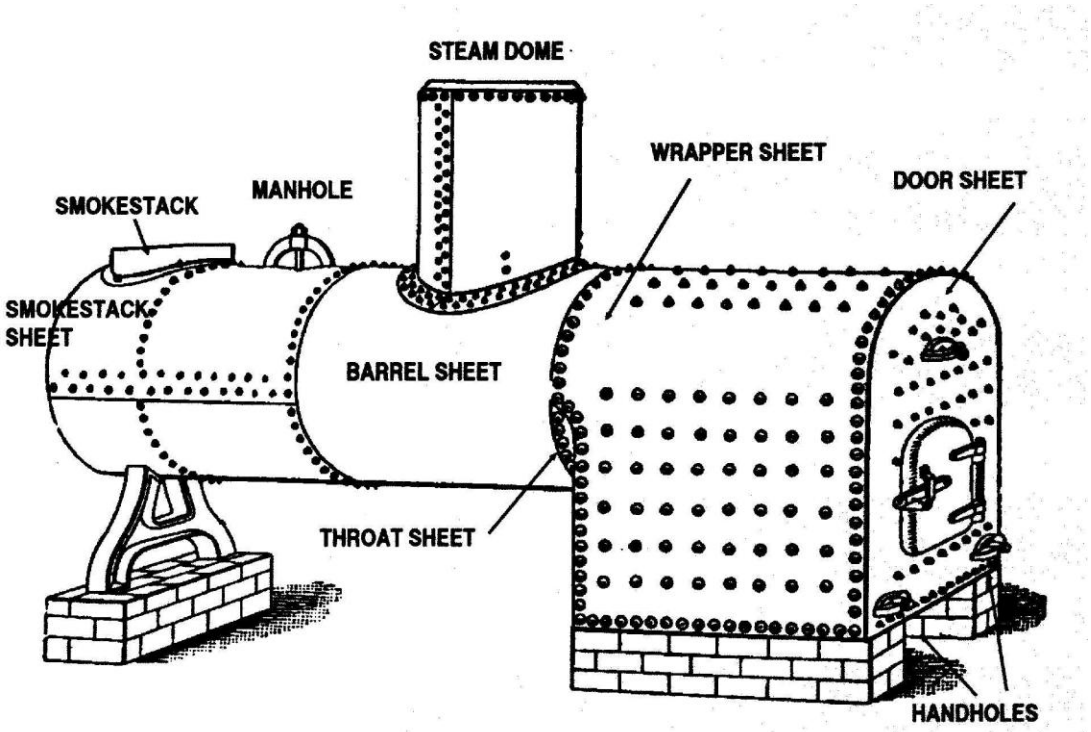
Bifurcated Tube

Chapter 5

FIRE TUBE BOILERS

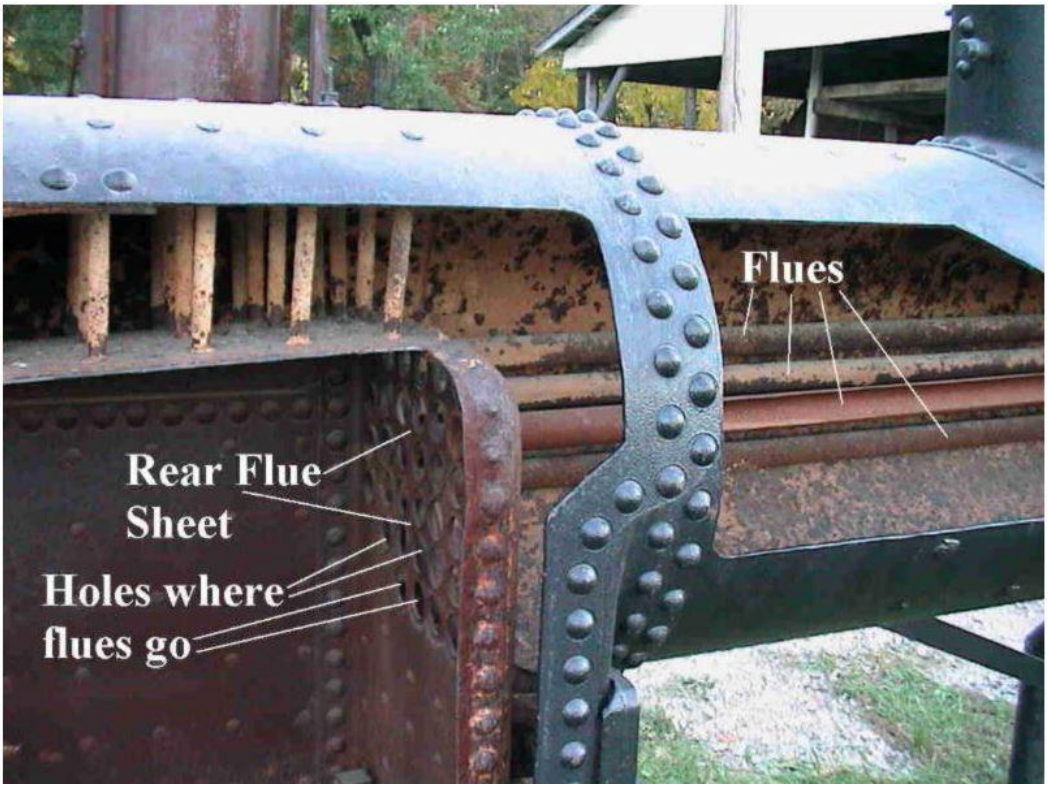
LOCOMOTIVE BOILER

The locomotive boiler is an adaptation of the boilers used in railway service. It consists of a cylindrical shell attached to an internally fired furnace. This boiler was used when all boilers were riveted. As a result the various sheets of steel that made up the boiler have different names.

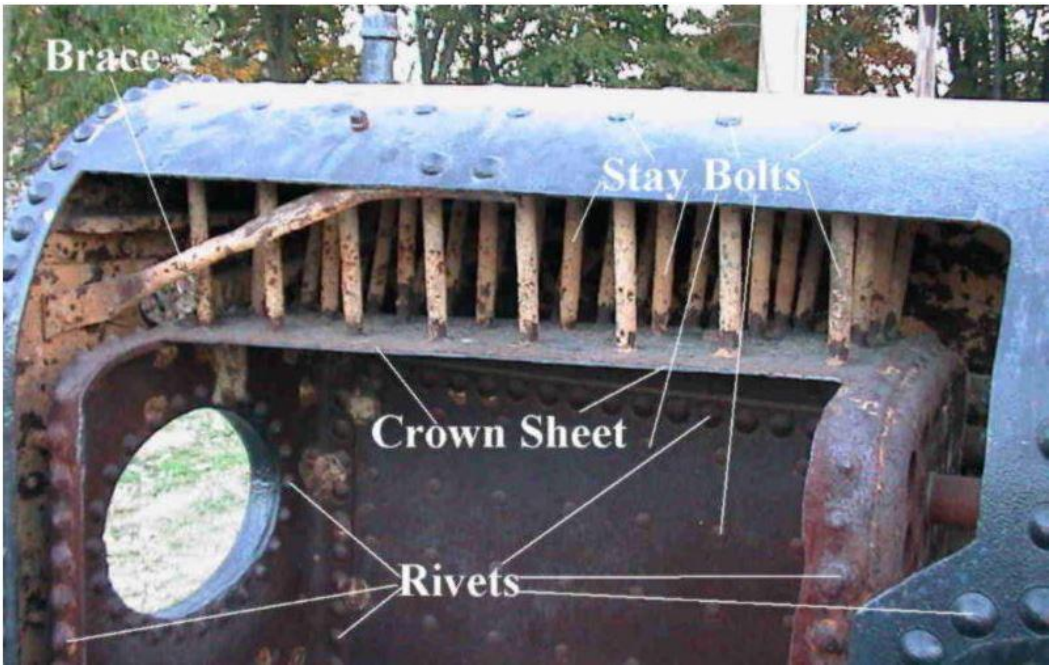


Stationary locomotive boiler

The wrapper sheet on the outside surrounds the crown and furnace sheets on the inside and the wrapper sheet is connected to the barrel sheet that surrounded the tubes. The door sheet is where the firing and ashpit doors are attached. Some locomotive boilers have a steam dome just as in railroad locomotives to provide dryer steam. The barrel sheet is the circular sheet that surrounds the tube bundle. The throat sheet is connected to the bottom of the barrel sheet. The smokestack sheet connects to the barrel sheet where the burned fuel exits from the tube bundle and up the smokestack. The barrel and smokestack sheet have a metal support mounted on brickwork. The firebox tube sheet is on the firing end of the tubes and the smokebox tube sheet is connected to the tubes nearest the stack.



The firebox tube sheet is clearly seen in this cut-away where the tubes or flues are attached. Note the rows of stays that are attached to the wrapper sheet to keep the crown sheet at the top of the firebox from collapsing inward from the boiler pressure.

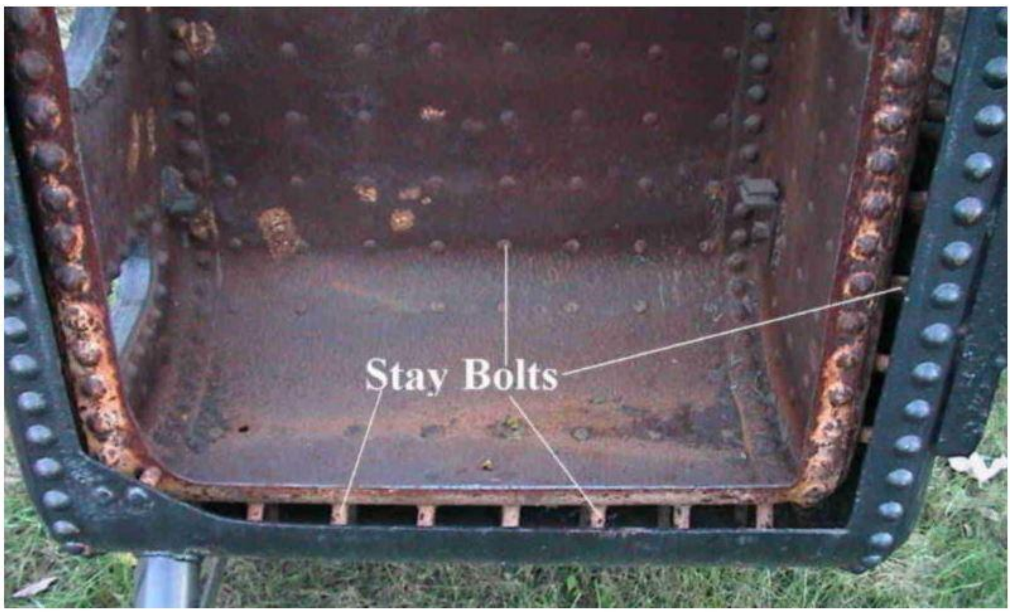


The Palm brace is attached between the wrapper sheet and the door sheet. Note how the firebox is riveted to the door sheet with the opening for the firing door.

Handhole opening to inspect the insides of the boiler.
Firebox door opening. Used to add fuel to the firebox.
Draft control door opening. Also used to clean ashes from the firebox.

The handhole opening at the top of the door sheet is to allow washing soft scale and mud off the top of the crown sheet.

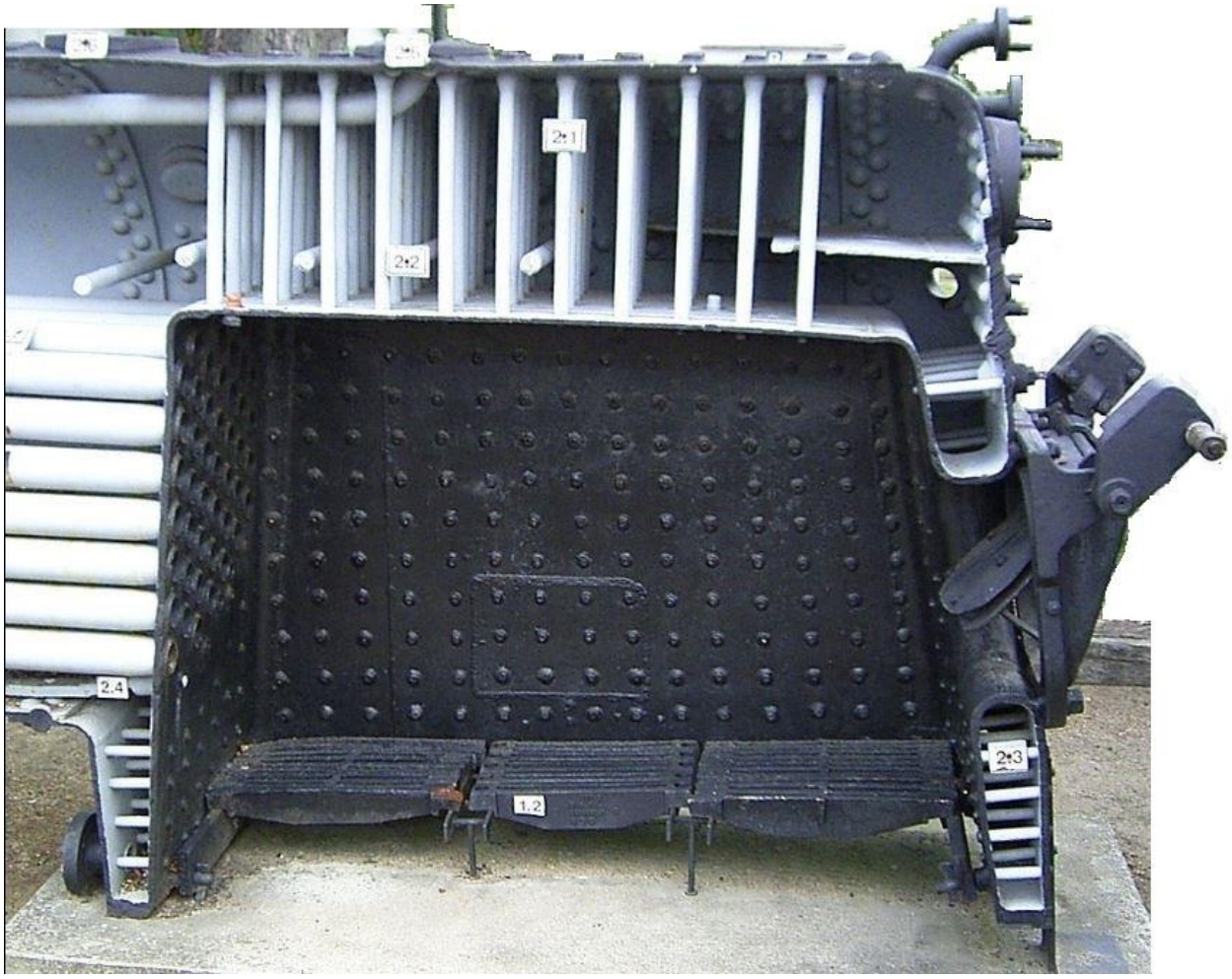
Grates would be fitted just above the draft control door to hold the fuel bed and run the length of the firebox. The Fireman will open the firebox door just long enough to fling in a shovelful of coal. He will try to cover any holes in the fuel bed to even the bed. A foot control on the butterfly doors is sometimes used so he can step down on the mechanical opener as he flings the fuel.



Notice the stays at the bottom of the firebox. These extend all the way up the side of the wrapper sheet and firebox sheet that have been cut away to allow you to see the construction, The water space between the outside sheets and the firebox sheets is known as the water bottom. A blowdown valve will be attached to the water bottom to allow the removal of mud that settles to the bottom.

This is looking at the rear of a stationary locomotive boiler where the smoke will come from the tubes or flues and go up the large hole at the top where the missing smokestack would be attached. The steam dome at the top of the boiler is where the steam will be taken from to prevent water from carrying over to the stationary steam engine or heating system, depending upon the need. The dry pipe has proven to be a better design and that is why most of the other boilers use it.

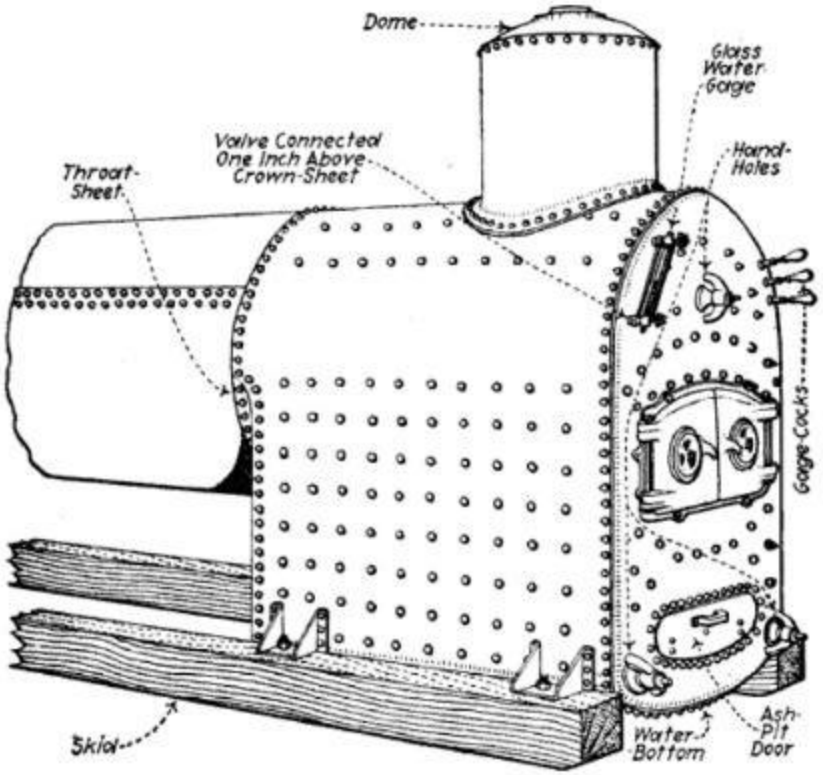
The handhole at the bottom of the throat sheet is for washing the mud down the blowdown when the boiler is shut down and drained.



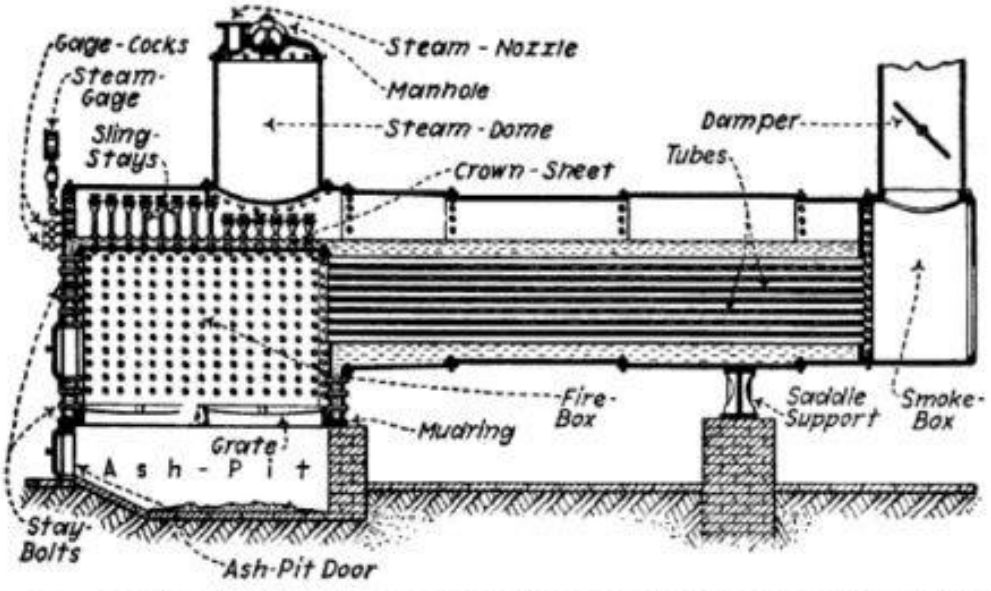
In this cut-away of locomotive boiler; note the narrow water spaces around the firebox. There is a blowdown connection at the lower left to drain the mud from the tube sheet water leg. There would be two handholes or washout plugs on either side of the firing door on the front for cleaning when the boiler is out of service and cool. Any place where mud can settle out is a place where overheating can occur.

Note the difference between this open bottom and the water bottom of the previous boiler. The firing grate will dump ash directly on the ground.

Note that there appears to be two "hard patch" repairs to this firebox where a large replacement sheet of steel has been welded in and another smaller patch welded over a hole in the replacement sheet. Then the sheet is re-riveted to the wrapper sheet. This is highly unusual to find a patch on top of a patch.



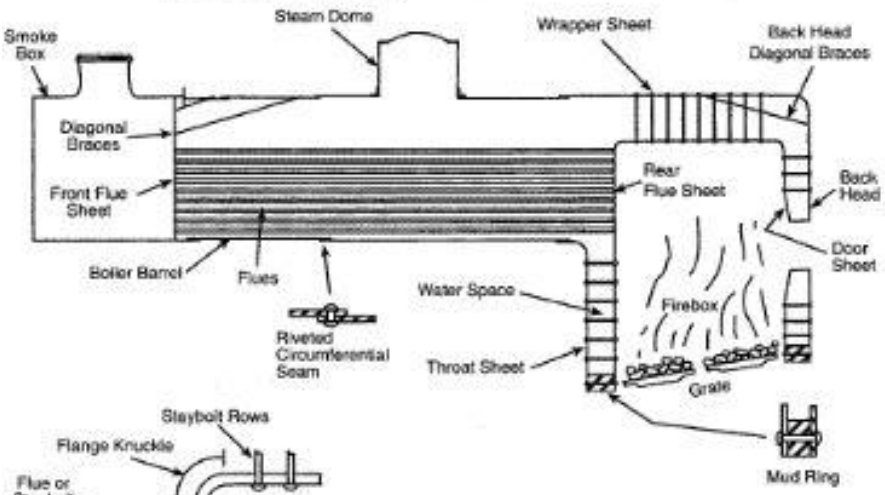
Fire-box end of locomotive-style of stationary boiler with water bottom.

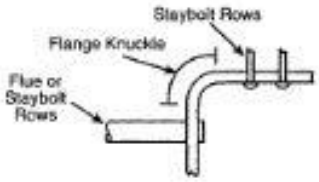


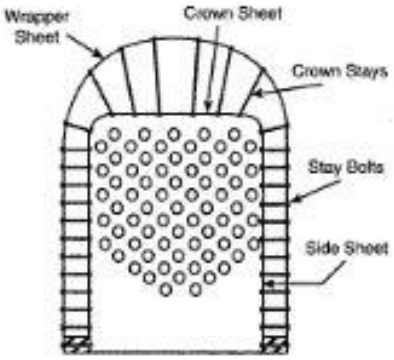
Sectional view of locomotive type of boiler as used in stationary practice.

BOILER: STAYED AND UNSTAYED SURFACES

Section Through Locomotive Boiler







SECTION THROUGH FIREBOX

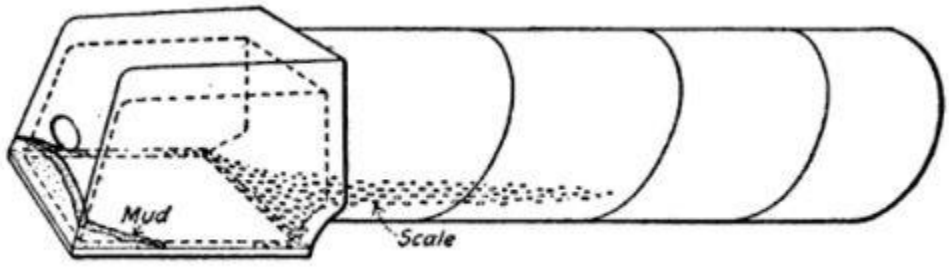
BOILER STAYED SURFACES

- Front Flue Sheet
- Rear Flue Sheet
- Wrapper Sheet
- Door Sheet
- Side Sheets
- Crown Sheet
- Throat Sheet
- Back Head
- Stayed Section of Thermic Syphons

BOILER UNSTAYED SURFACES

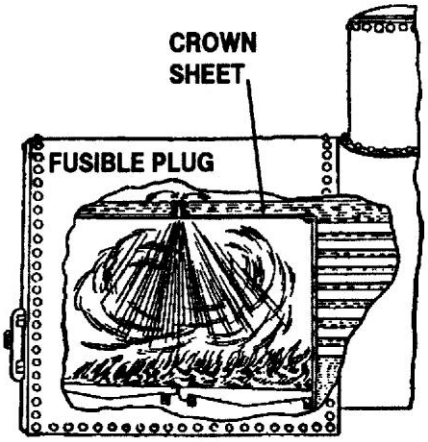
- Boiler Barrel
- Steam Dome
- Arch Tubes
- Thermic Syphon Neck
- Firebox Circulators
- Knuckle Section of Flanged Sheet

This figure shows the many types of stays needed to keep the different steel sheets together. The expansion and movement between the firebox and wrapper sheets may need Tate flexible staybolts to handle the movement. Note that this locomotive boiler has water legs and an open ashpit rather than a water bottom.



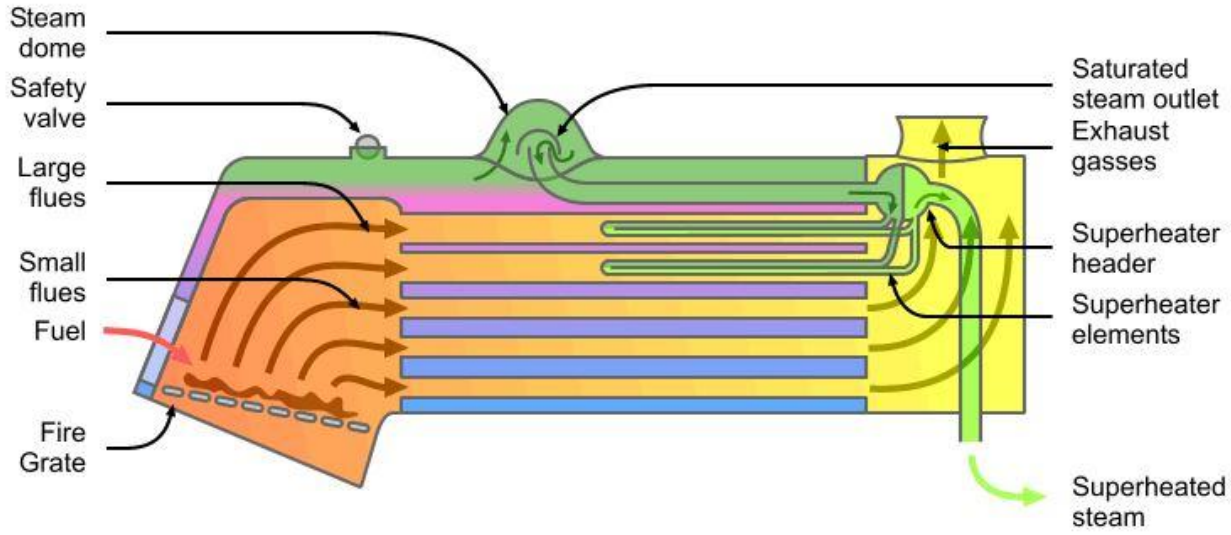
Mud and Scale Accumulations

Important points to remember about the Locomotive boiler are:

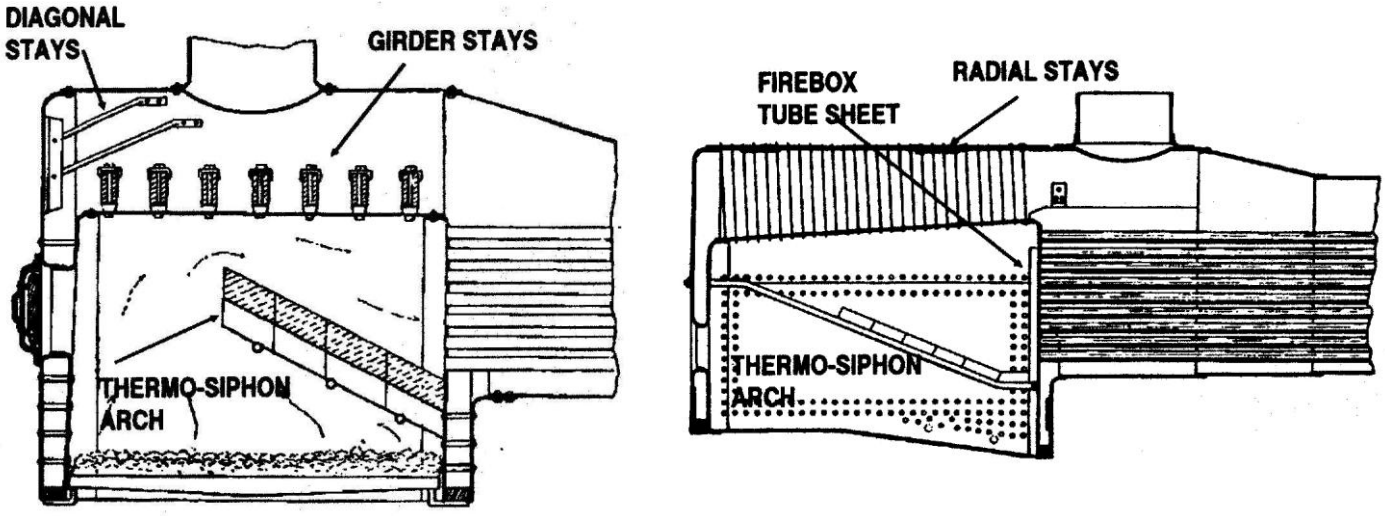


Fusible Plug in crown sheet

1. The fusible plug is located in the top of the crown sheet, and projects through the sheet not less than one inch.

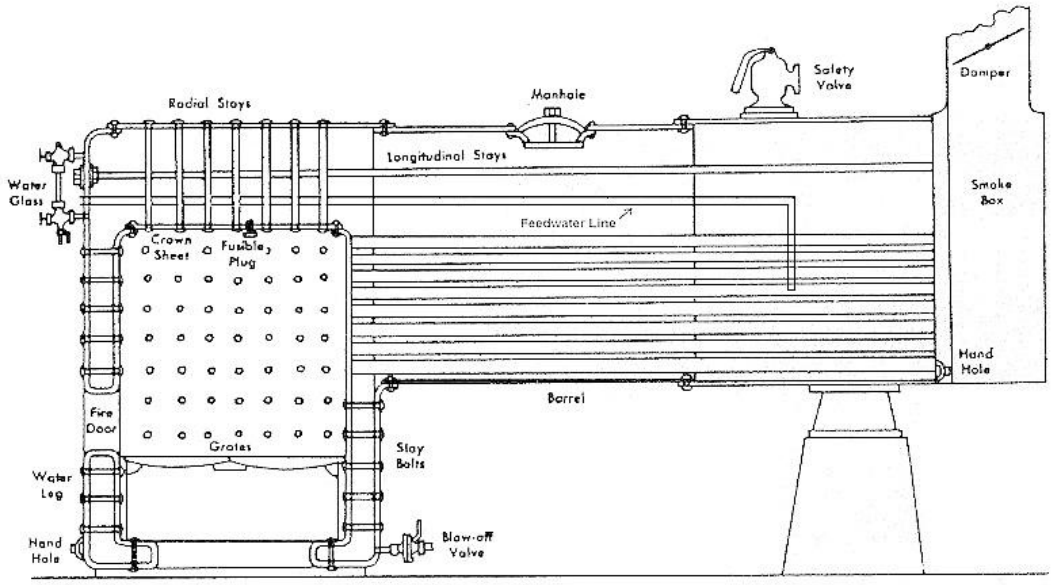


2. The water rises around the sides of the furnace and over the top of the furnace, moves toward the smokestack end of the boiler and falls between the tubes.



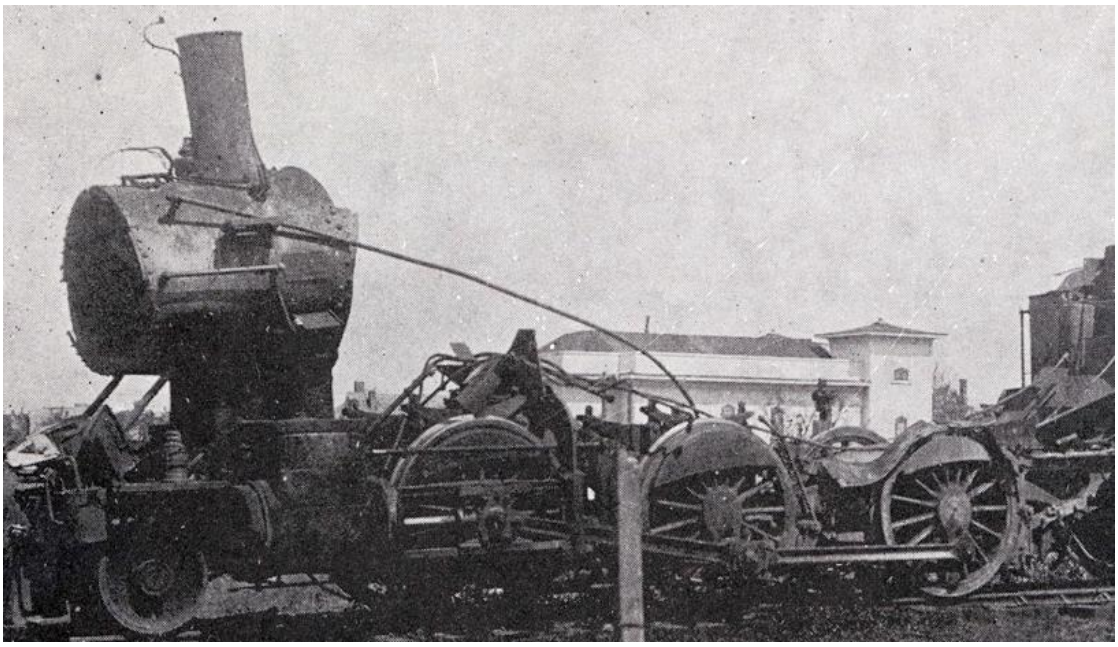
3. This is a one gas pass boiler and as such is not economical to operate. Sometimes arch tubes are used in the furnace to increase efficiency. On occasion a baffle known as a thermo-siphon arch is used to force the combustion gasses to follow an "S" path before reaching the tubes to increase efficiency. The thermo-siphon arch increases efficiency by creating turbulence in the furnace while slowing down the gasses so they stay in the furnace longer, allowing the boiler to absorb more heat. This turbulence also eliminates dead air pockets in the furnace.

4. The boiler can be mounted on cast iron skids to allow easy transport to remote locations like portable sawmills.



This is an excellent drawing to use if the Examiner asks you to draw a locomotive boiler for your exam

5. Feedwater enters this boiler on the side, or through the door sheet, about 1/4 of the way from the smokestack end. It enters about 1/2 the way up from the bottom and discharges between the tubes. Cold feedwater should never be discharged near the furnace sheets. Note the water legs on bottom.

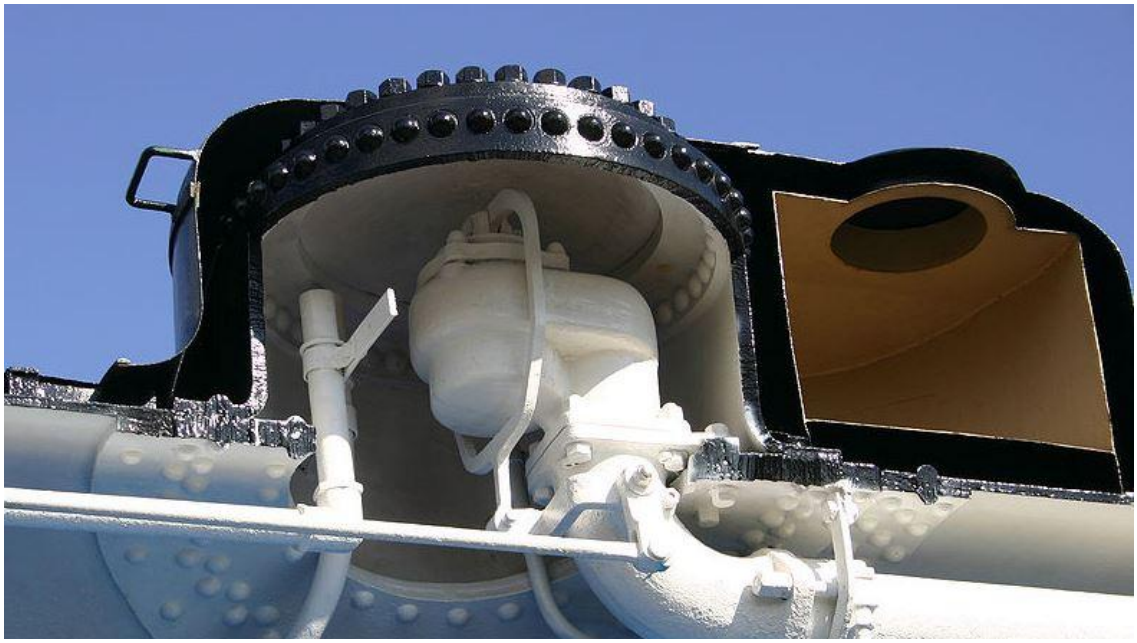


6. The first place to overheat in case of low water is the crown sheet. The lowest safe water level is three inches above the crown sheet. This is the remains of this railway locomotive boiler after the crown sheet collapsed and the boiler exploded.

Water Column and sightglass on Locomotive Boiler

Note the safety valve popping on this stationary boiler

7. The water column is attached at the top to the door sheet or wrapper sheet and at the bottom 18 inches above the bottom of the boiler.



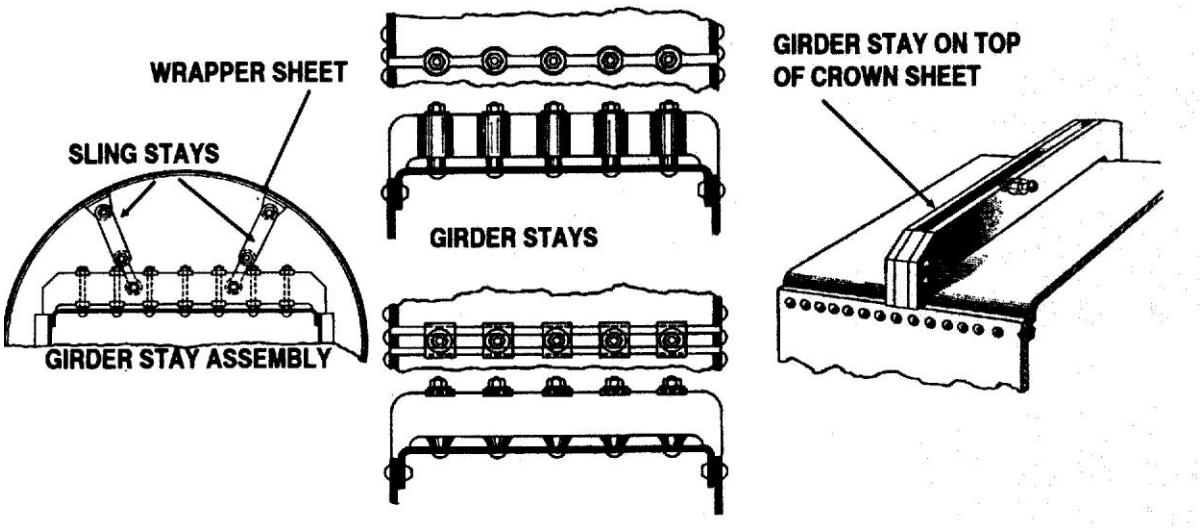
Steam Throttle inside Steam Dome with bolted manhole cover

8. The manhole is usually located in the steam dome. In some cases the steam dome can be unbolted to provide access to the tubes. .If there is no steam dome then the manhole is located in the top of the shell. A manhole is required if the boiler shell is over 48 inches in diameter.

9. Handhole plates are provided to wash the top of the crown sheet and the bottom of the waterleg. Sometimes two inch brass washout plugs take the place of the handholes.

10. The boiler is pitched to the furnace and the blowdown valve is attached to the lowest part of the waterleg at the reinforcing pad to drain the sediment that gathers there.

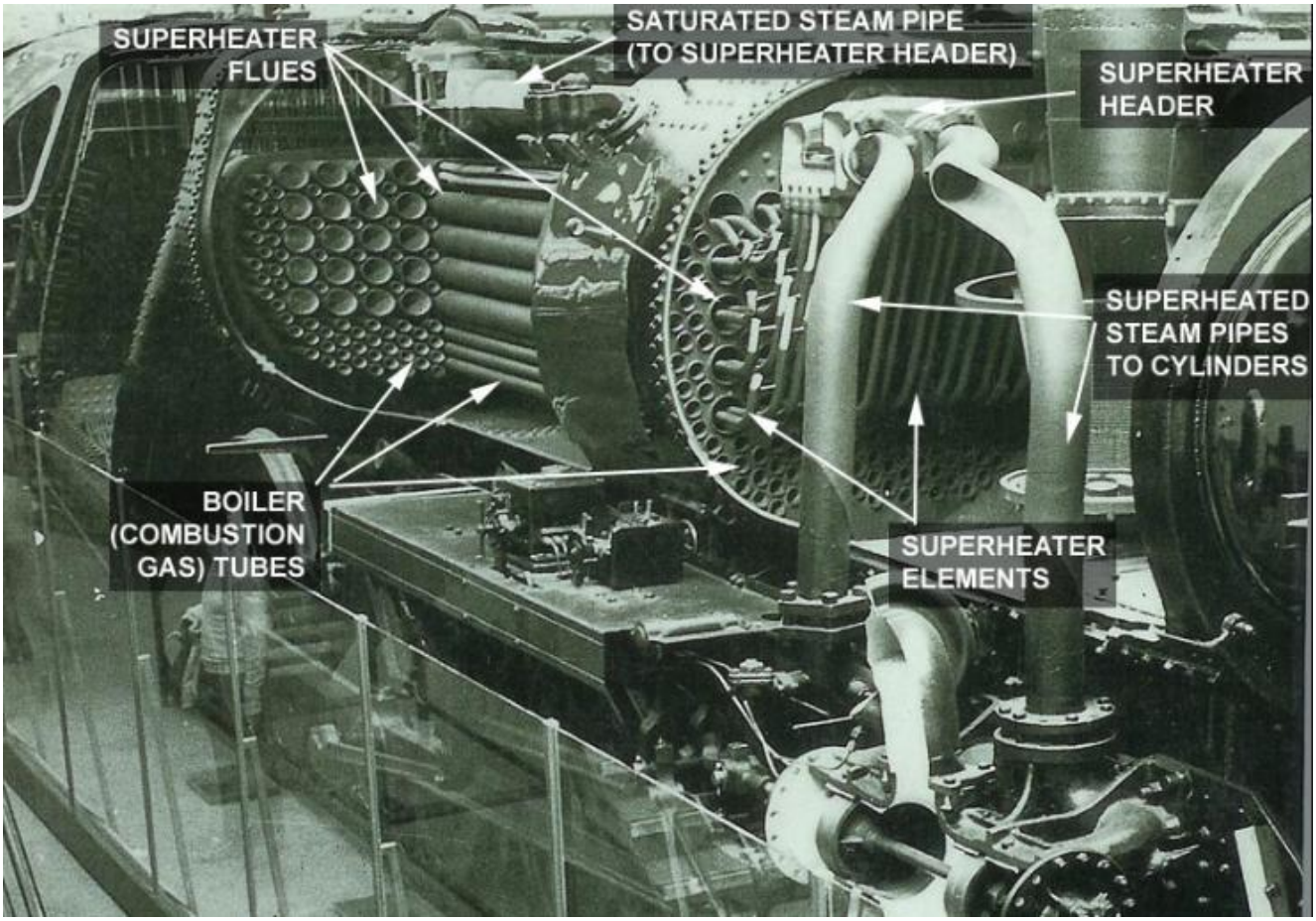
11. In railroad practice the smokestack end is referred to as the front of the boiler, in stationary practice the furnace end is referred to as the front end.



12. This boiler requires many types and numbers of stays. Girder stays are found on the top of some crown sheets.

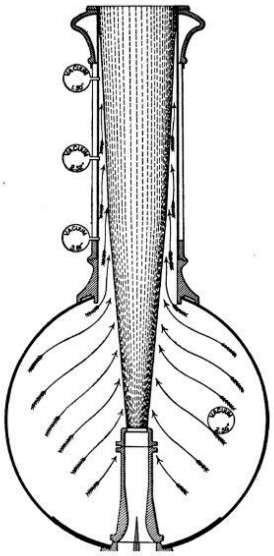
The radial stays support the crown sheet and are attached between the crown sheet and the wrapper sheet.

13. Expansion of the furnace is sometimes taken care of in large locomotive boilers by corrugating the furnace sheets. Some railway locomotive furnaces are very large.



14. A locomotive boiler used in a boiler room or for portable service has fewer tubes than a locomotive used for the railroad, but they are larger in diameter. Tube sizes in stationary boilers are usually between two to three inches while in railroad practice they are around 1 and 1/2 inches. Sometimes railroad boilers have larger tubes to allow for the insertion of superheater tubes.

Locomotive Superheater



15. In a railway locomotive boiler the exhaust of the steam engine is run through a venturi in the stack to increase the draft. The reciprocating motion of the steam engine causes the characteristic puffing of the smoke seen rising out the stack in old movies. The steam billowing from around the front of the engine as it pulls into the station is due to the Engineer in the cab opening drain valves on the steam engine cylinders to keep condensate from forming in the cylinder while the engine is stopped. After the engine is started and runs several yards, the engineer closes the drain valves again.

16. The maximum pressure on a locomotive boiler usually does not exceed 300 psi.

17. Traction engines, which are steam tractors with locomotive style boilers used for farming and hauling in the early 1900's, had to go down a steep hill in reverse so that the water will cover the crown sheet and not overheat the boiler and cause the fusible plug to melt.

ADVANTAGES OF THE LOCOMOTIVE BOILER

1. It is less expensive to construct because it does not use any brick setting and is compact, needing less headroom than other types of boilers.

2. It can be transported to the jobsite complete and ready to hook to the water, steam and drain lines.

3. All tubes are the same length and diameter, making replacement and keeping spares on hand easier.

DISADVANTAGES OF LOCOMOTIVE BOILERS

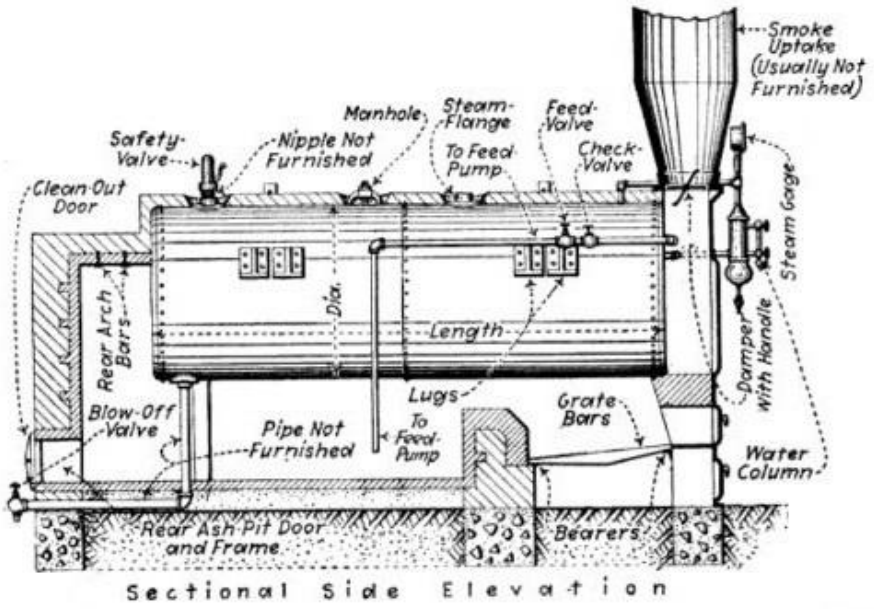
1. It requires extensive staying, which is a source of weakness

2. The stays interfere with cleaning the waterside of the boiler.

3. You cannot change fuels for added efficiency due to the factory set dimensions of the combustion chamber.

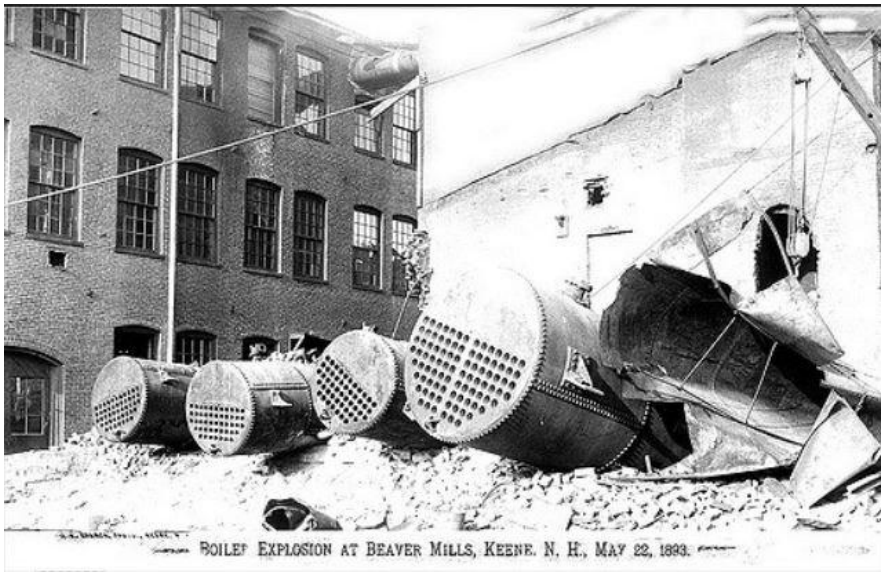
4. You cannot fire the boiler heavily without risking damage to the furnace sheets.

HORIZONTAL RETURN TUBULAR BOILER (HRT)

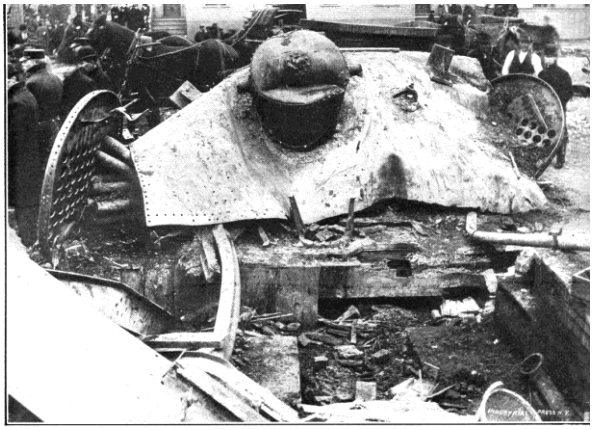


Illustrating standard equipment for return-tubular boilers.

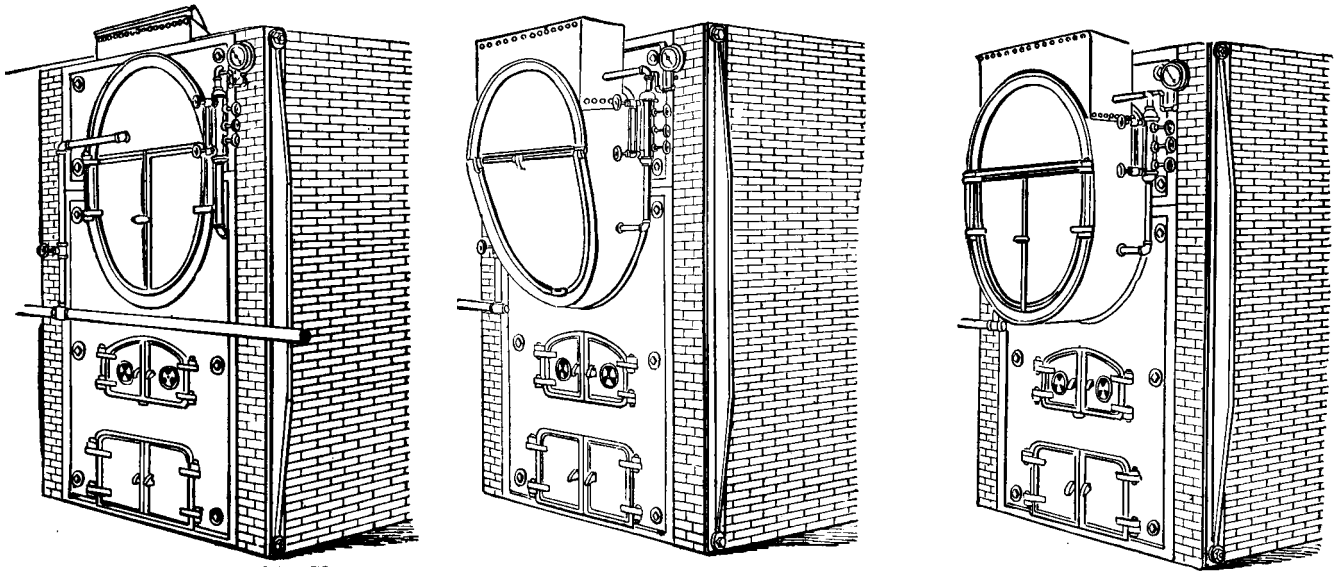
The HRT or Horizontal Return Tubular was one of the most widely used boilers, and is the reason that so many boiler examinations refer to it. Its popularity has been superseded in recent years by the modern dryback Scotch Marine boiler. It is simple to construct and its large water capacity helps it to handle sudden steaming demands.



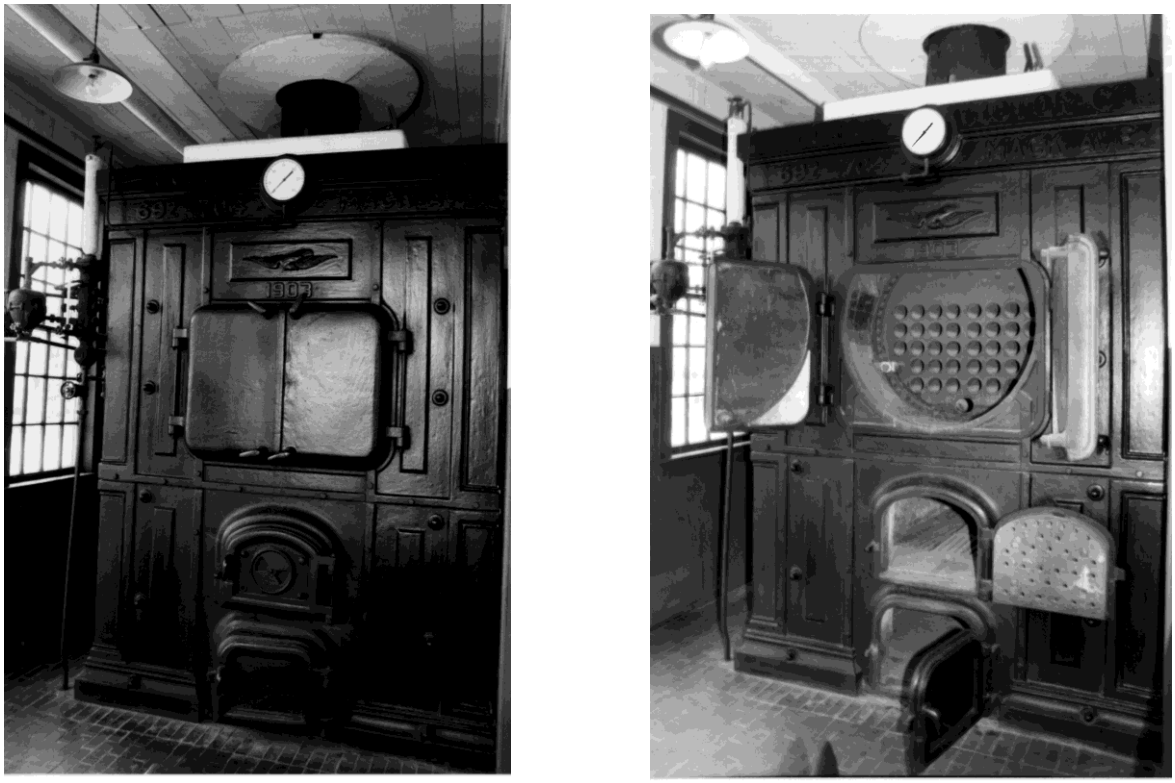
BOILER EXPLOSION AT BEAVER MILLS, KEENE, N. H., MAY 22, 1893.



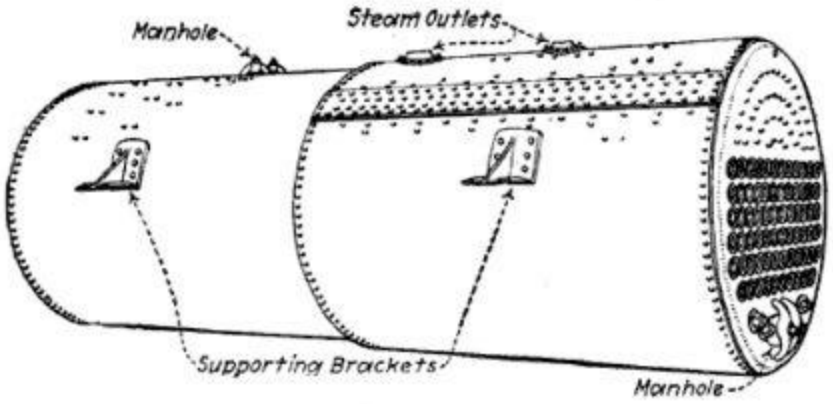
Because the shell is exposed to the action of the fire, the large water capacity also makes the boiler more dangerous should some part of the boiler fail.



There are two general types of Horizontal Return Tubular boiler, the flush front and the overhanging front types.

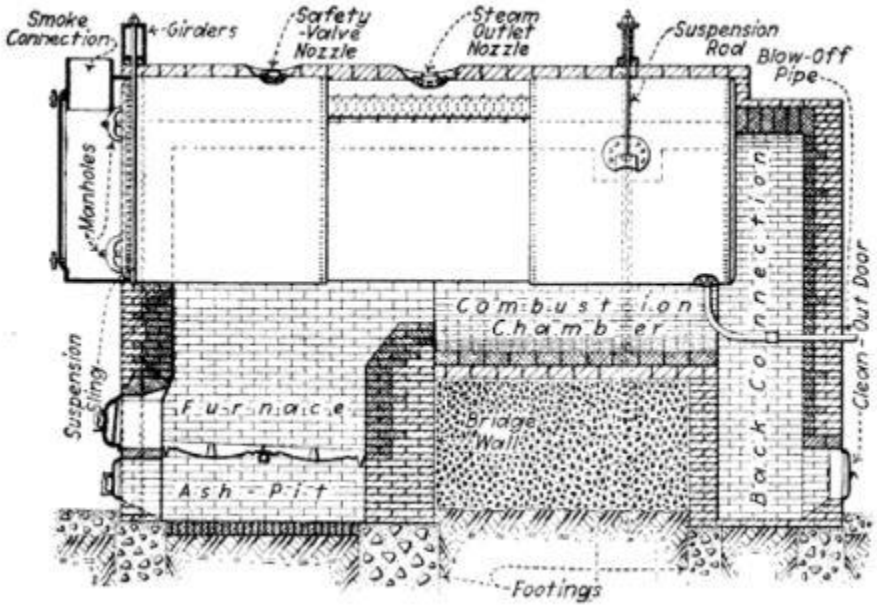


Flush Front HRT's with doors closed and doors open

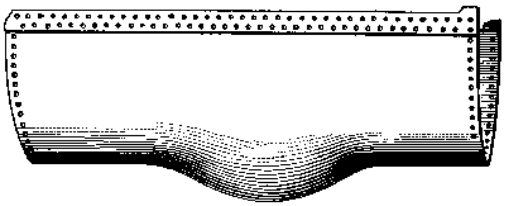


Horizontal return-tubular boiler with supporting brackets.

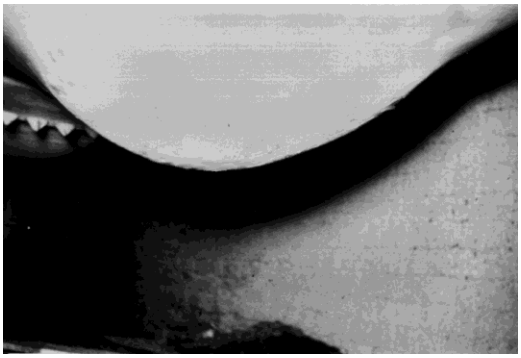
The boiler consists of a cylindrical shell with circular flat plates on either end. In the past, the edges of the circular plates were turned inward at the rear and inward or outward at the front to allow a surface for riveting. The circular seam in the middle was known as the girth seam and the horizontal seam was known as the longitudinal seam. The reason that the girth seam was necessary was that the Code did not allow a longitudinal seam longer than 12 feet.



If the HRT was very long, three sheets of steel were used and there were two girth seams. The cylindrical sheets or "courses" were riveted into each other. The middle course was always inside the front course to protect the seam from flame impingement. The longitudinal seam was always outside the brick setting to protect it from the fire. Shell diameters range from 36 to 96 inches. Shell thickness varies from 1/4 inch to 3/4 inches.

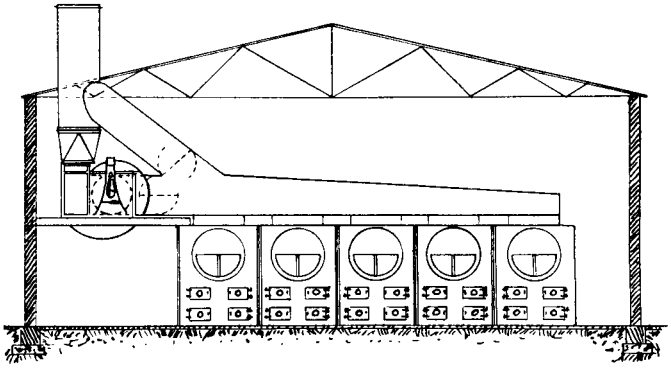


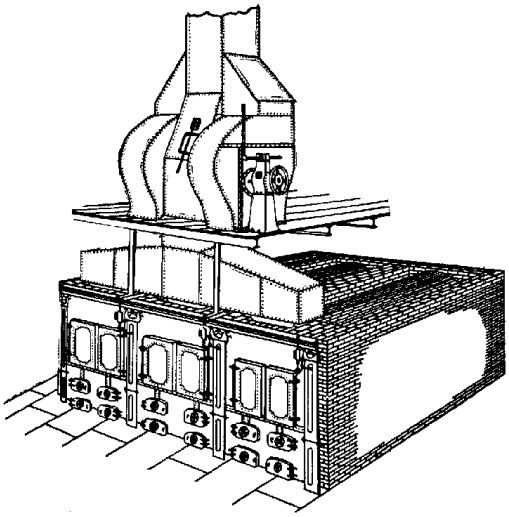
Bag on bottom of HRT furnace sheet



Bag on HRT Boiler Inside Furnace

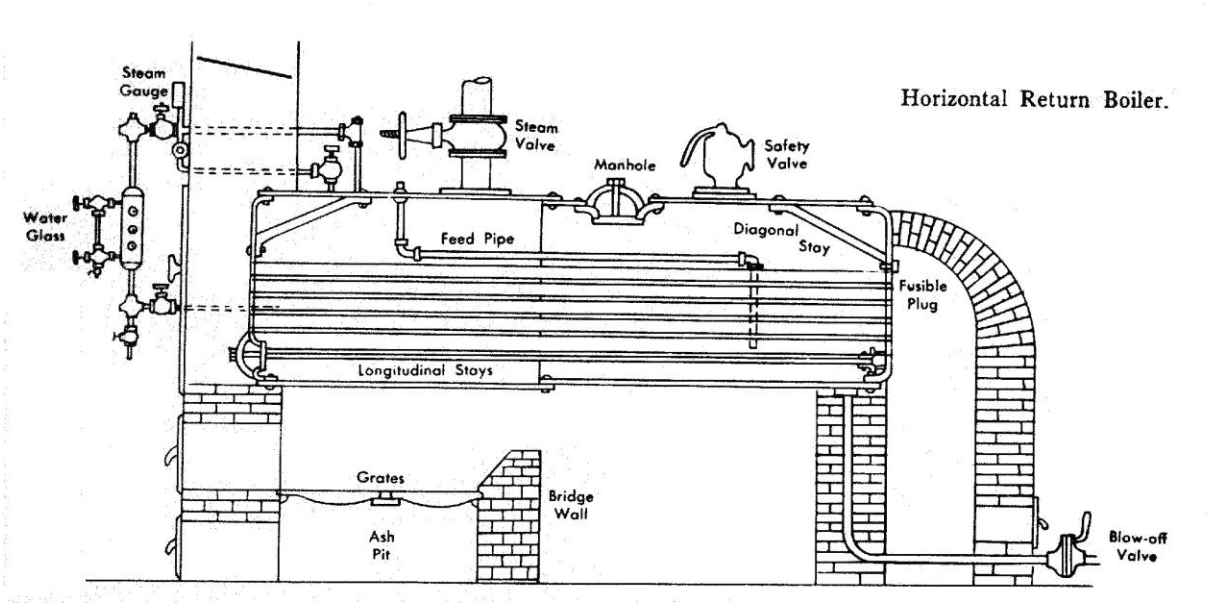
The maximum pressure for an HRT is around 200 psi. If the diameter or the pressure were increased beyond these limits, the steel would be so thick that the water in the boiler could not cool the steel, resulting in a bag or blister.



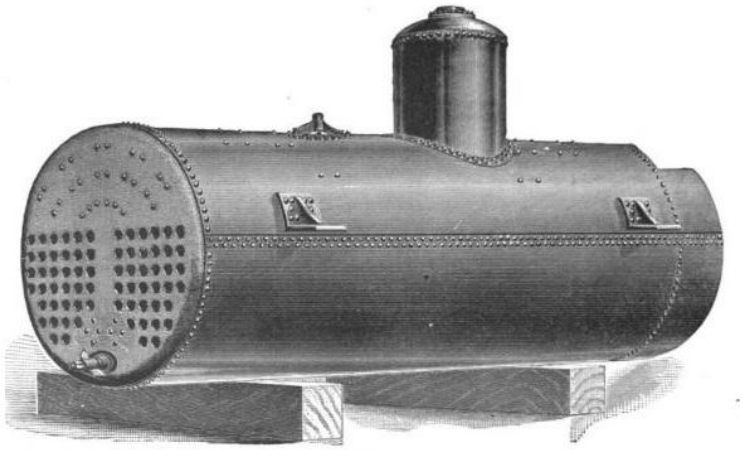


When more than one boiler was needed to provide the necessary steam, a row of boilers was arranged in a "Battery". The examiner will draw a simple sketch of 2 boilers in battery and you will have to draw the location and explain the purpose of all the necessary valves to operate the boilers successfully. We will explain the location of the valves later in this PDF.

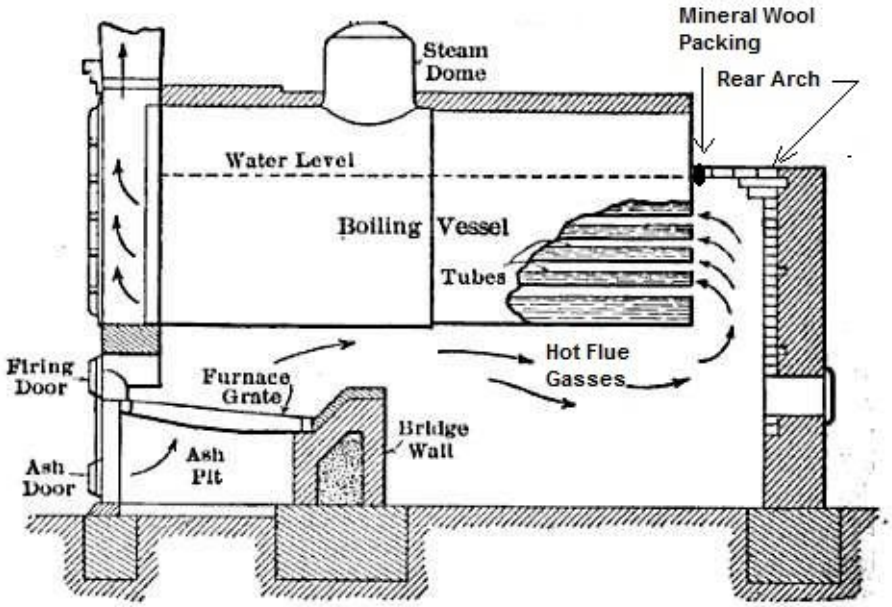
Important points to remember about the H.R.T are:



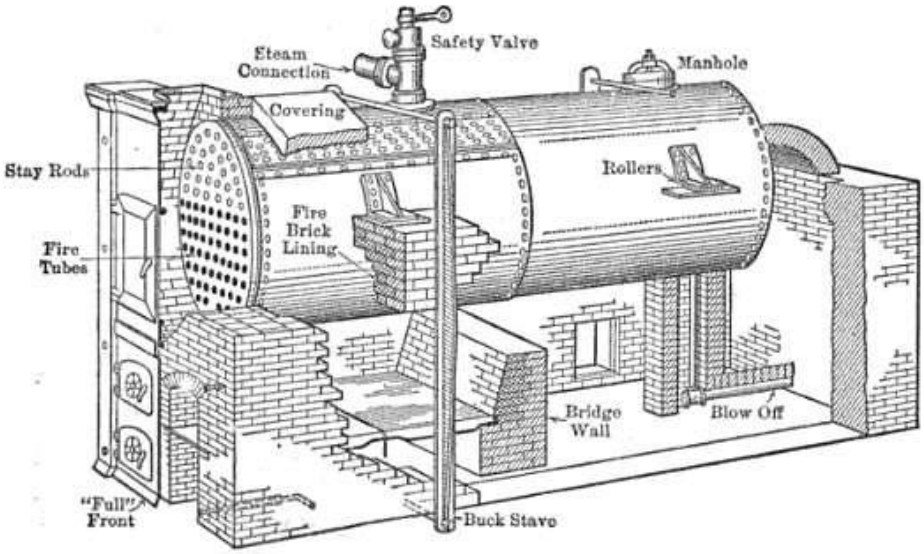
1. The fusible plug is located not less than 1 inch above the top row of tubes to the center of the plug in the rear tube sheet. The only exception to this is if the distance from the top of the tubes to the top of the shell is 13 inches or less, but the plug can never be lower than the top row of tubes.



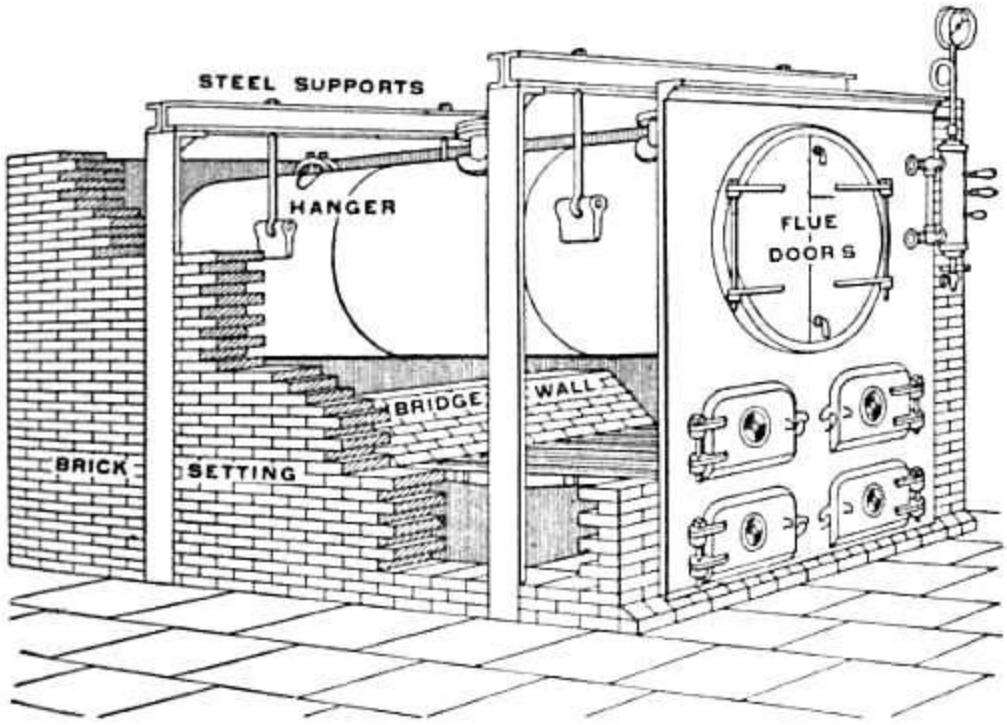
2. Sometimes the center row of tubes, or two vertical rows of tubes on either side of the centerline are left out to aid in water circulation. The water circulation varies from the front of the boiler to the rear. Remember that heat causes the water to rise. Since in the front of the boiler the shell is exposed directly to the fire, while the combustion gasses going through the tubes at the front of the boiler have cooled, the water rises along the inside of the shell and falls down the center. At the rear of the boiler, the exact opposite occurs. The hot combustion gasses are passing through the tubes causing the water to rise in the center of the tubes and fall down around the inside of the shell.



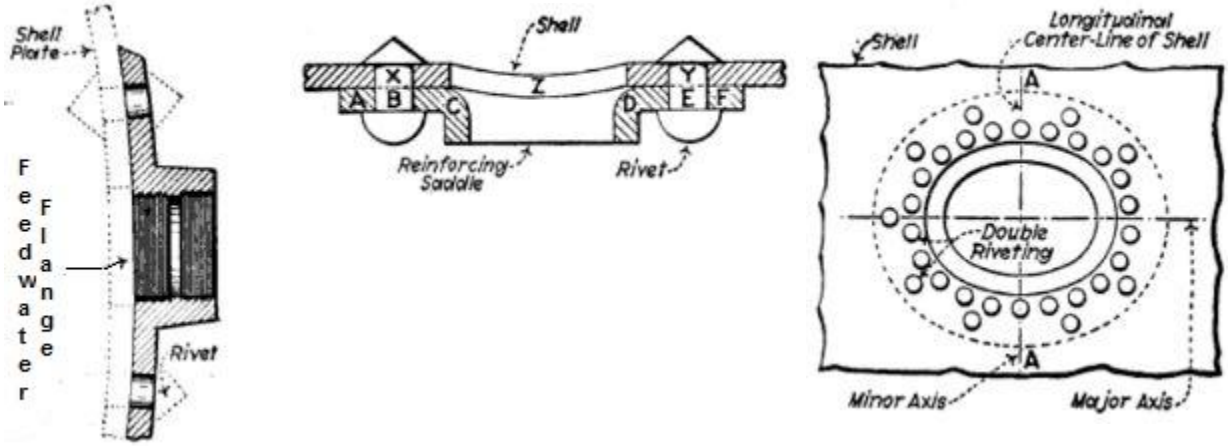
3. The products of combustion pass over the bridge wall and follow the bottom of the shell toward the rear of the boiler. A special arch of brickwork is built at the rear to direct the gasses back through the tubes toward the front of the boiler and up through the breeching and out the stack. This arch connects to the rear head of the boiler about three inches above the top row of tubes. The 1 inch space between the arch and the shell is packed with mineral wool or asbestos to prevent the products of combustion from leaking out. Cast iron arch bars support the brickwork that make up the arch. An Operator should avoid standing on this arch, for if it should fail while the boiler is firing, the Operator would fall to a most unpleasant demise.



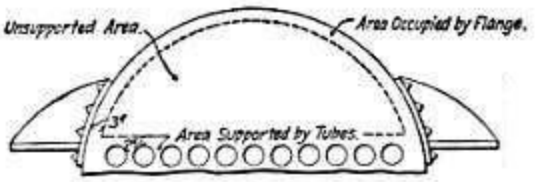
4. The expansion is toward the rear. In the smaller sizes, the shell has two supporting brackets riveted or welded to each side of the shell. The rear brackets are usually mounted on rollers to allow the boiler to move when heating or cooling. The weight of the boiler is supported by the brickwork, reinforced with Buck Stays, I-beams on the outside of the brick.



In the larger sizes, the weight of the boiler would cause too much crushing stress on the brickwork. In these cases, the boiler has a supporting framework of steel I beams at front and rear. Steel suspension slings are connected to the I beams on one end and the supporting brackets on the other end. This allows the boiler to expand freely without putting stress on the brickwork. The Code requires this method if the boiler is over 72 inches in diameter.

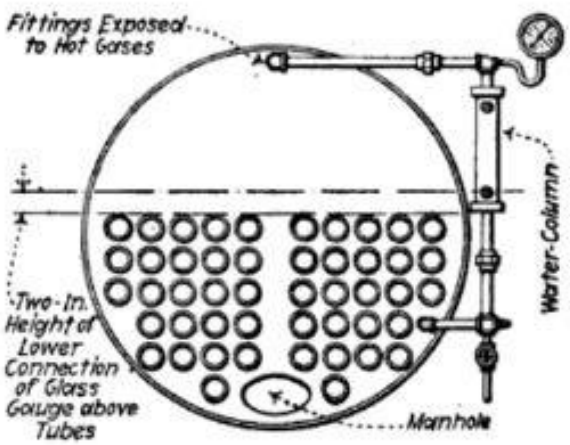


5. The feed line enters the front or top of the boiler and travels 3/5 of the way into the boiler before discharging between the tubes. The feed line, blowdown line, safety valve, steam outlet, and manholes must have special flanges attached to the shell to allow attachment of the appliances and piping. The internal feed line is supported by steel hangers inside the shell.

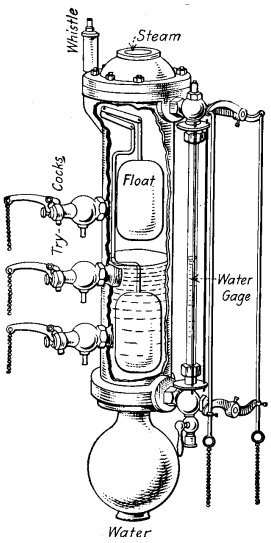


Unsupported Part of Boiler Head.

6. The first place to overheat in case of low water would be the top row of tubes. Notice the diagonal stays that support the front tube sheet where there are no tubes

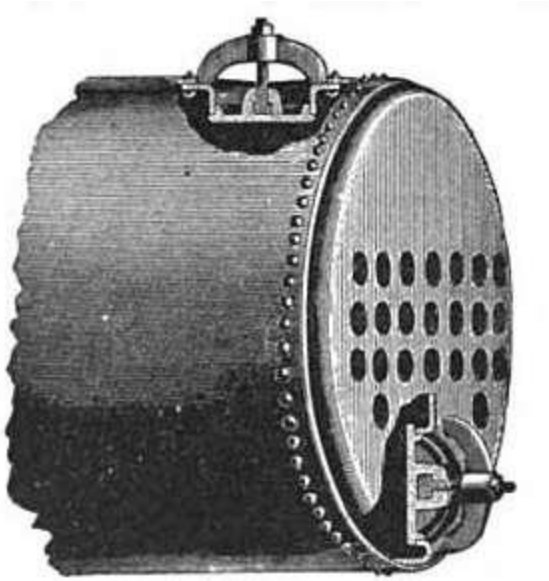


Water column set at proper height.

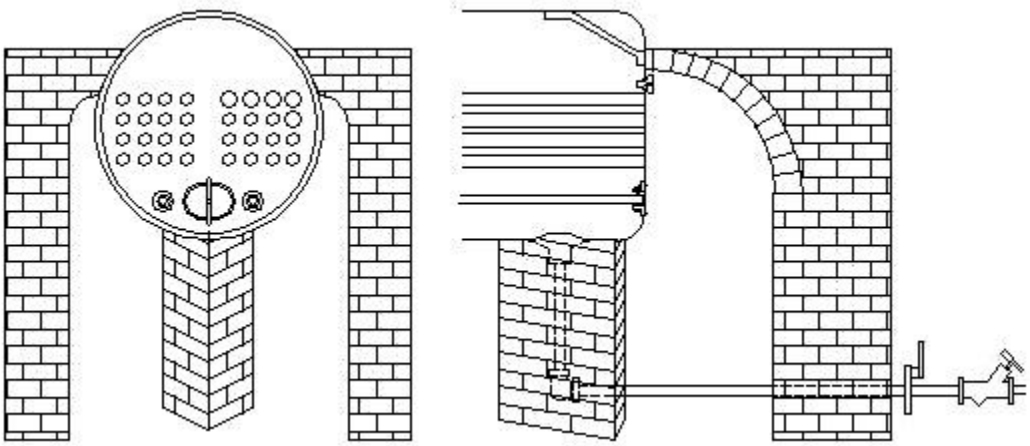


Detail of Water Column

7. The water column should be attached so that there is three inches of water above the tubes when the water is at the bottom of the sight glass. The steam connection is either at the top of the front tube sheet or at the top of the boiler. The water connection is at the lower third of the front tube sheet.



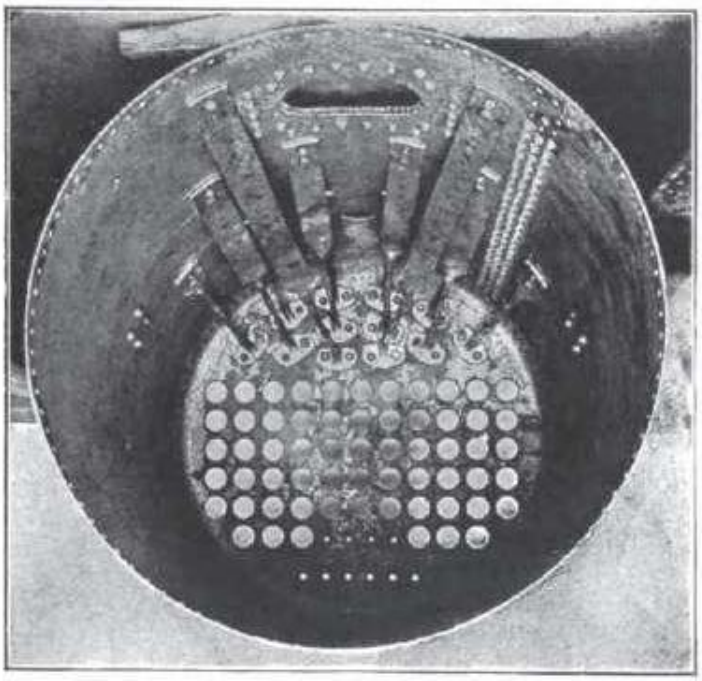
8. If the boiler is less than 48" in diameter, there will be one manhole in the top of the boiler. If the boiler is over 48" in diameter, then the Code requires that another manhole be placed in the front head below the tubes.



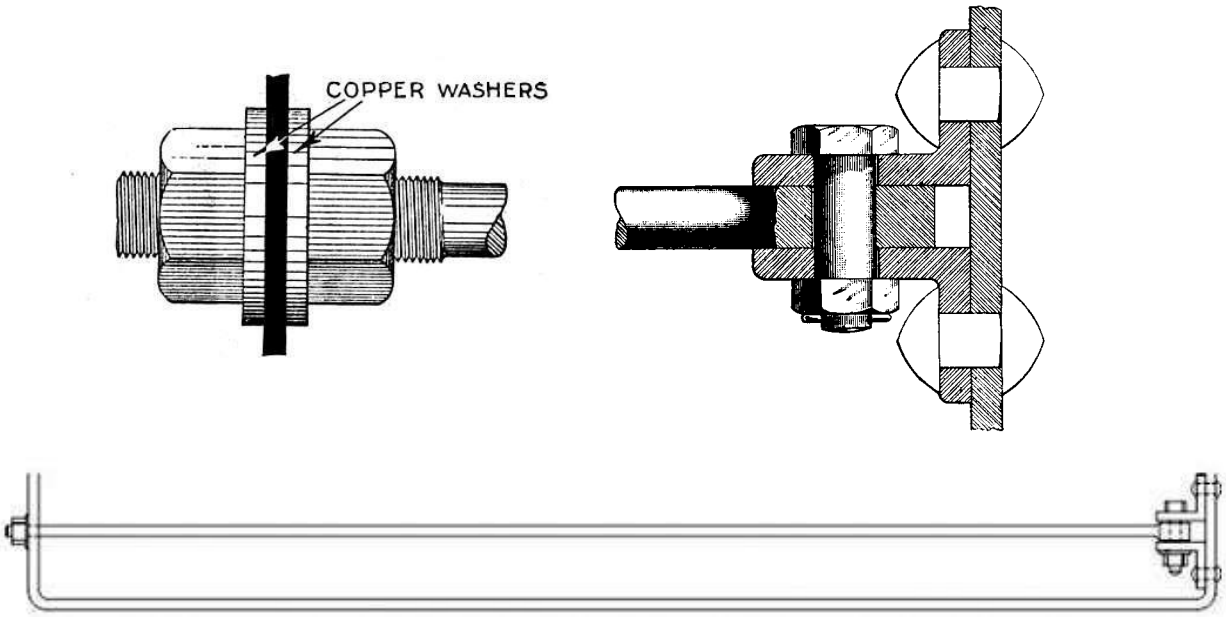
9. A V wall of brick is placed in front of the blowoff pipe to protect it from fly-ash impingement and also to keep it from burning due to poor water circulation. The blowoff or blowdown pipe is connected to the bottom rear of the boiler. The pipe extends through an asbestos packed sleeve through the brick wall at the rear of the boiler and the blowdown valves are located outside the boiler. This allows the blowdown line to move freely with the boiler. The metal sleeve should not extend past the brick inside the boiler or else it could burn off. Asbestos has been outlawed for most powerplant uses but many of the old plants still have asbestos in pipe and boiler insulation, valve packing, and gaskets.

10. The shell pitches downward from 1 to three inches toward the rear for drainage.

11. Diagonal stays are used in the upper portion of the boiler to support the heads and to allow more room for access to the inside of the boiler above the tubes. The pipe in the center of the upper picture houses the water level probe.

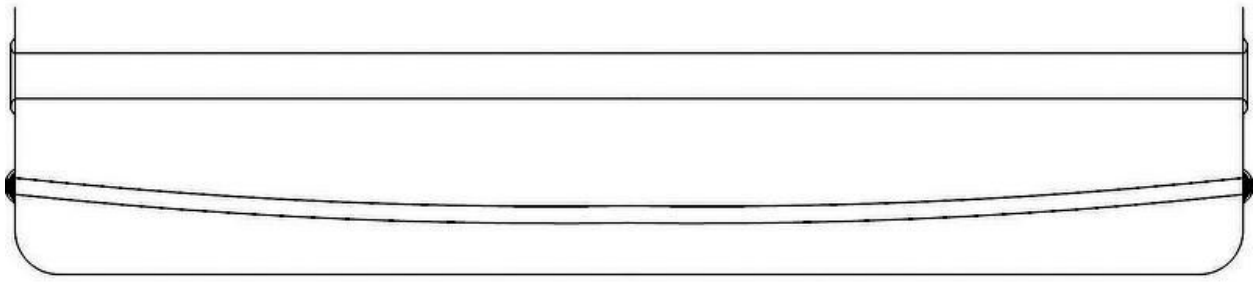


Scully Braces on HRT above Tubesheet



Through-to-head stays are used below the tubes to support the end plates. The reason for using through-to-head stays is that if the stay were to extend past the rear tube sheet, the fire would burn the end off. The tubes themselves act as stays in the central portion of the tube sheet. Through-to-head stays are used below the boiler tubes instead of diagonal stays because there is not enough room below the tubes for the diagonal stays without crowding them together. This crowding would cause problems with water circulation, buildup of scale, and access to the bottom of the boiler through the lower manhole.

HRT showing through stay nuts and manhole in the front tubesheet



The through stay can bow if the boiler is overheated and the stay stretches beyond its elastic limit. The elastic limit is the ability of steel to resume its original length after being subjected to a pulling stress. When the boiler cools back down, the stay is now too long and will have a bow in it.

12. The tubes are flared and beaded. All fire tube boilers should have the tube ends beaded to prevent the flared portion from burning off in those areas subject to high temperatures.

13. The tubes take up 2/3 of the water space in the boiler.

14. This is a two gas pass boiler.

15. When cleaning the boiler for inspection, the upper bricks of the V wall should be removed to allow the inspector to see the blowoff connection at the boiler shell.

16. The heads are usually 1/16 of an inch thicker than the shell.

Goodway Soot a Matic

17. The fire side of the boiler is cleaned of soot by opening steel doors in the front of the boiler to get access to the tubes and running a cylindrical wire brush attached to a long rod through the tubes. Soot is unburned carbon from the fuel. Modern soot cleaning devices attach a vacuum cleaner to a motorized cable that makes cleaning easier with less soot being blown around the boiler room.

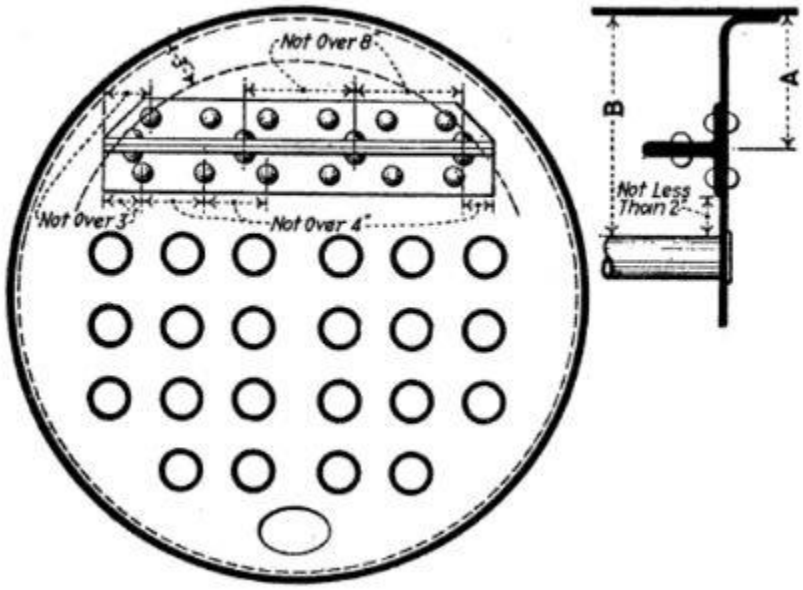
18. The combustion chamber in an HRT is the area behind the bridge wall. The floor of the combustion chamber in a hand fired HRT boiler slopes from the bridge wall toward the rear of the boiler for easier removal of the ash and soot and is known as the flame bed.

19. The walls inside the furnace are made of firebrick and the floors are made of common brick.

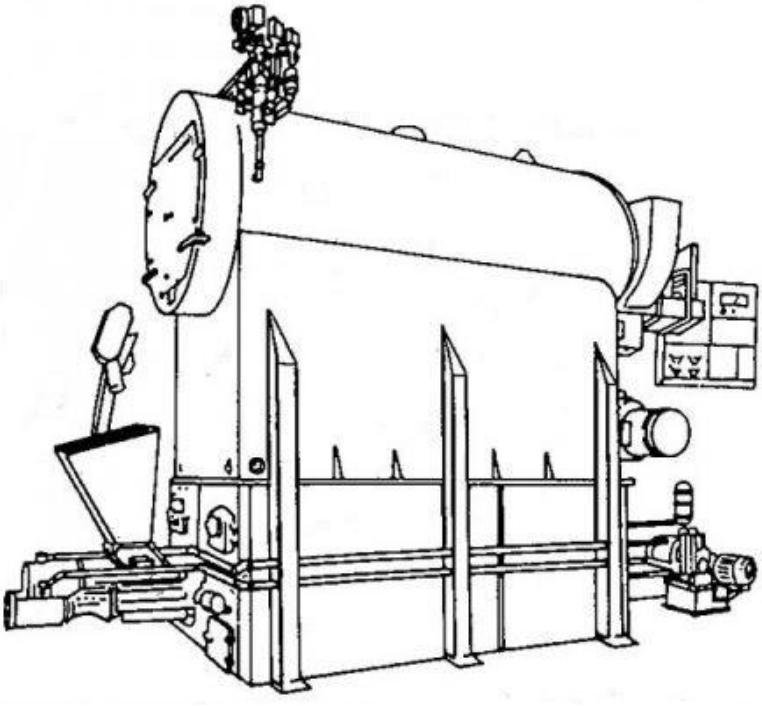
20. The Dry Sheet is the extension of the front course of the boiler beyond the front head that connects the boiler to the breeching. On the overhanging front type of HRT the dry sheet is entirely out of the furnace and therefore does not need protection from the fire. On the flush front HRT the dry sheet is inside the furnace and firebricks are built up above the firing doors to protect it from overheating.

21. "Buck Stays" are vertical steel beams outside the brickwork connected at the top by rods and turnbuckles to prevent the brickwork from sagging outward.

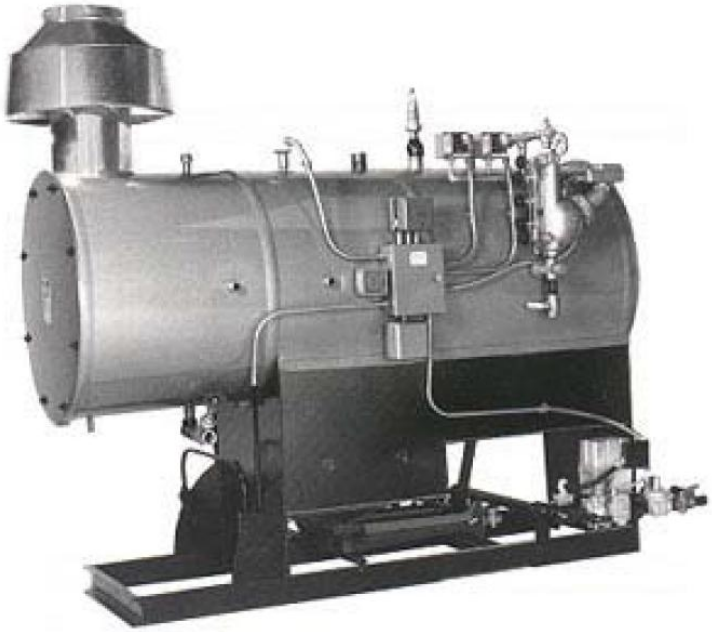
22. A "strongback" is a steel beam that is attached temporarily to the circular end sheets of the HRT. It is used to prevent the end sheets of an HRT from collapsing during construction when the diagonal stays are being installed. After the tubes are installed the strongback is removed.



23. When the HRT is less than 36 inches in diameter and the pressure is less than 100 psi, angle iron or other steel bracing can be attached to the outside of the shell instead of using diagonal stays.



The CNB Tri-Fuel HRT boiler could burn gas, oil, or coal. Columbia Boilers of Pottstown PA. is one of the few manufacturers still making HRT boilers in the United States. They have been making boilers for 70 years.



The Lattner Boiler Company's HRT boiler is made in Cedar Rapids, Iowa and has been in business since 1918.

ADVANTAGES OF THE HRT

1. It has greater ability to instantly flash water into steam when a sudden demand for steam is placed upon the boiler compared to other fire tube boilers. This is due to the larger amount of water storage in the HRT compared to other fire tube boilers.

2. It is the least expensive boiler to build that can raise steam efficiently.

3. It fits into boiler rooms without needing high ceilings.

4. Tube replacement is simple and one size of tube fits all tube holes. Sufficient floor space should be left in front of the boiler to allow tube replacement.

5. Since you build the furnace from brick to surround the boiler, the furnace can be designed to suit the firing characteristics of a particular fuel.

DISADVANTAGES OF THE HRT

1. It is more likely to explode than other types of boilers.

2. Riveted boilers have overlapping seams exposed to the direct action of the fire. Because these seams cannot get rid of the heat as rapidly as might be necessary, this is a weak point in the boiler. The Code states that if these plates are over 5/8 inches thick each, the outside plate must be milled down to 9/16 inches. If an HRT has two courses, the rear course must go into the front course.

3. The combustion gasses being light tend to rise at the rear arch and go through the top row of tubes, bypassing the lower rows and resulting in a loss of efficiency.

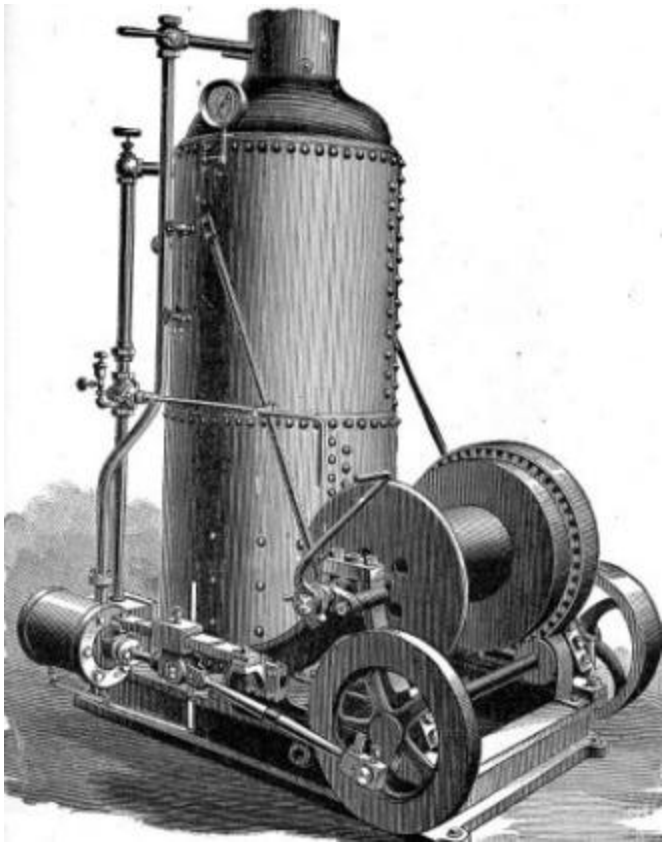
4. The water surfaces other than the top row of tubes and the upper shell are impossible to mechanically clean because the top row of tubes blocks access to the lower rows. The best solution is to keep a good water treatment program to avoid scaling the tubes. Acid cleaning should be a last resort due to the danger of damaging the boiler.

5. If too many tubes are crowded into the tube sheets, it impedes water circulation.

6. Due to the difference in temperature at the bottom and the top of the boiler, the boiler does not expand evenly.

7. If the boiler is fired too heavily, or if the water treatment is poor, overheating can damage the boiler. Either a blister or a bag can occur. A blister occurs when the steel is not entirely homogenous and the steel flakes off in a layer when overheated. A bag occurs when the steel shell above the fire overheats so badly it starts to droop into furnace. If it has not bagged too severely, it can sometimes be heated and driven back into place. If the bagging is severe, the bag is cut out and a new plate is welded flush with the boiler shell. Riveted boilers have the patch placed inside the boiler. If the patch uses bolts it is called a soft patch. If the patch uses rivets it is a called a hard patch.

VERTICAL FIRE TUBE BOILERS



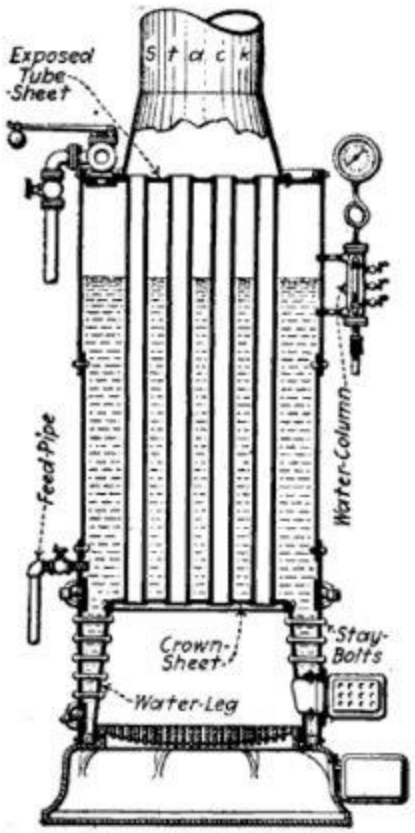
The vertical firetube boiler was used for steam hoisting engines and other work that required a boiler that was portable and could be taken to different job sites.

The antique fire engines were horse-drawn wagons and later motorized vehicles that used a vertical boiler that powered a duplex pump. Suction hoses were then dropped into any nearby source of water and the discharge hoses from the pump were used to battle the blaze.

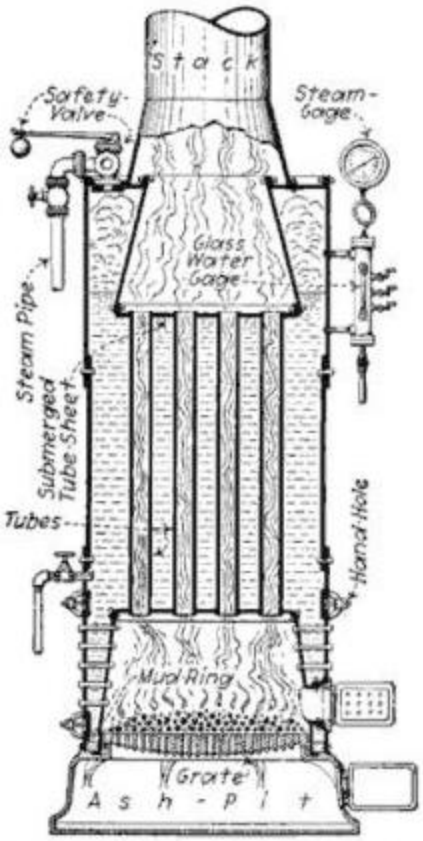
A steam donkey was a vertical fire tube boiler on wooden skids that was hooked to a steam engine winch for hauling fallen trees out of the woods. If the log got stuck and the Operator did not relieve the tension quickly enough, the steel cable could snap and go flying through the woods cutting down anyone in its path.

Steam rollers that paved the first asphalt roads were so common the name is still used today when referring to gasoline or diesel engine powered rollers.

Vertical Boilers were used in early steam cranes (above) and on narrow gage railways (below).

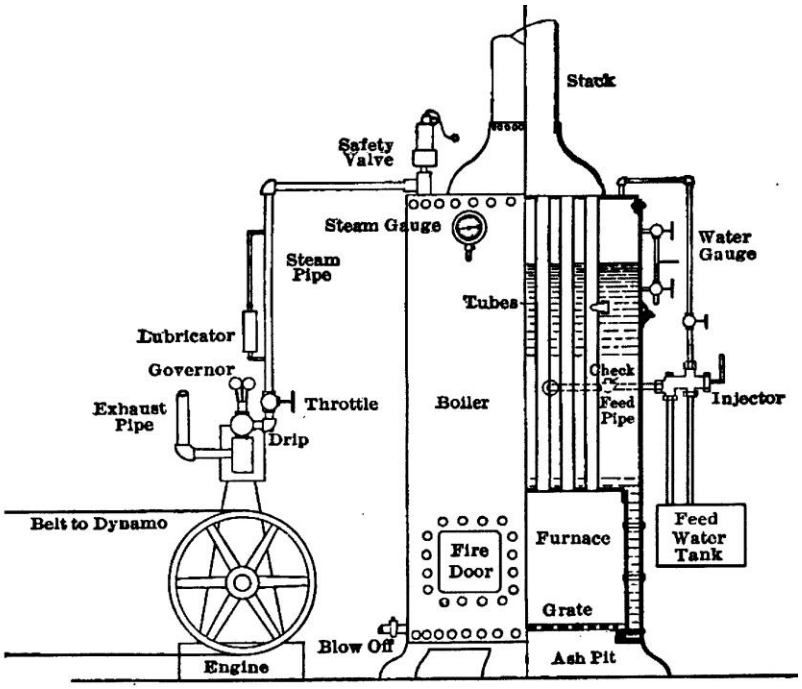


Semiportable upright fire-tube boiler having non-submerged tubes.



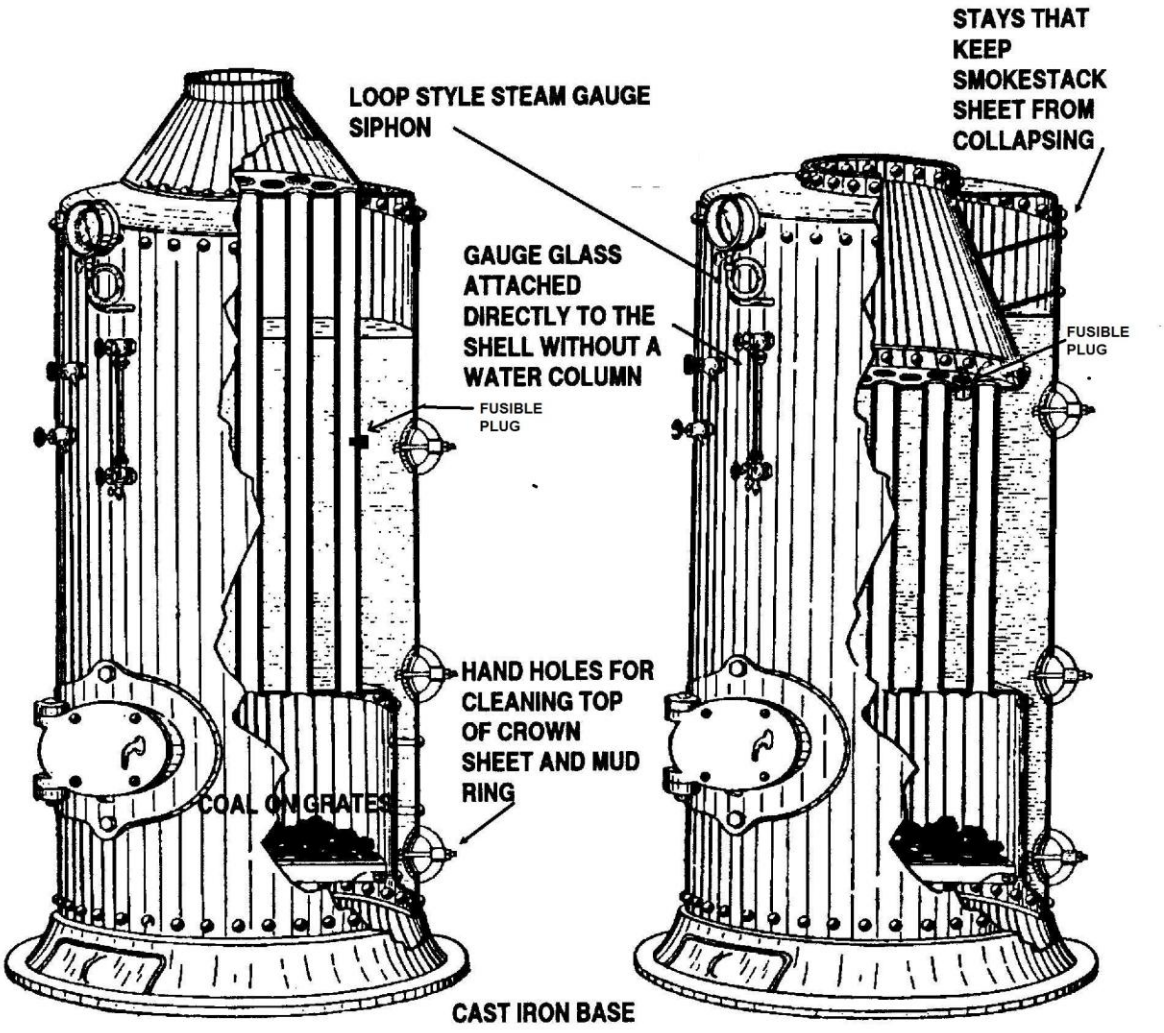
Upright boiler with submerged tubes.

There are two general type of vertical fire tube boilers, the dry top and the wet top or submerged tube type. The dry top vertical fire tube boiler has the tubes exposed to the steam at their upper ends. The wet top or submerged vertical fire tube boiler has its tubes completely under water.



The boiler consists of an inner or furnace shell and an outside shell. The inside or furnace shell is subject to a collapsing pressure and the outside shell is subject to a bursting pressure. The inside shell is the weaker of the two because the pressure is trying to deform the inner shell while the outside shell is trying to be forced into a more perfect cylindrical shape. This figure shows a dry top vertical boiler with an injector water feed, a fusible plug, a steam outlet with a safety valve, and a water gage glass tapped directly to the shell.

Important points to remember about vertical fire tube boilers are:

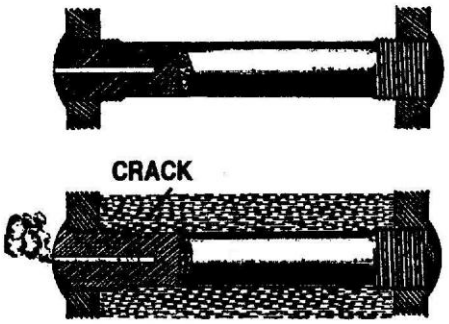

STAYS THAT KEEP SMOKESTACK SHEET FROM COLLAPSING
LOOP STYLE STEAM GAUGE SIPHON
GAUGE GLASS ATTACHED DIRECTLY TO THE SHELL WITHOUT A WATER COLUMN
FUSIBLE PLUG
FUSIBLE PLUG
HAND HOLES FOR CLEANING TOP OF CROWN SHEET AND MUD RING
COAL ON GRATES
CAST IRON BASE

1. The fusible plug on the dry top vertical boiler is located in an outside tube, not less than one third the length of the tube above the lower tube sheet. This tube is made heavier than the rest to provide enough threads to install the fusible plug. A hand hole is located in the shell opposite the fusible plug to allow access to change the plug. The fusible plug on the wet top boiler is located in the top of the tube sheet and projects through the sheet not less than one inch.

2. The water circulation is up over the furnace and down around the sides of the shell.

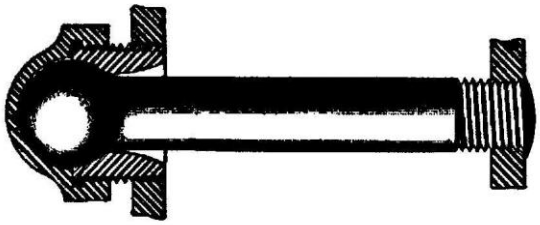
3. This is a one gas pass boiler. The flue gasses go straight up the tubes and out the top. They are not economical to run but their portability is better than any other boiler.

4. The staybolts tend to break at the inside edge of the outer shell. This is because the inside furnace sheet is expanding and contracting more than the outside sheet and the staybolt is cooler toward the outside sheet. This constant flexing is similar to holding a wire steady in one hand while you move the wire up and down with the other hand. The wire breaks at the point of the wire that is remaining stationary.



Staybolt with tell-tale before and after cracking

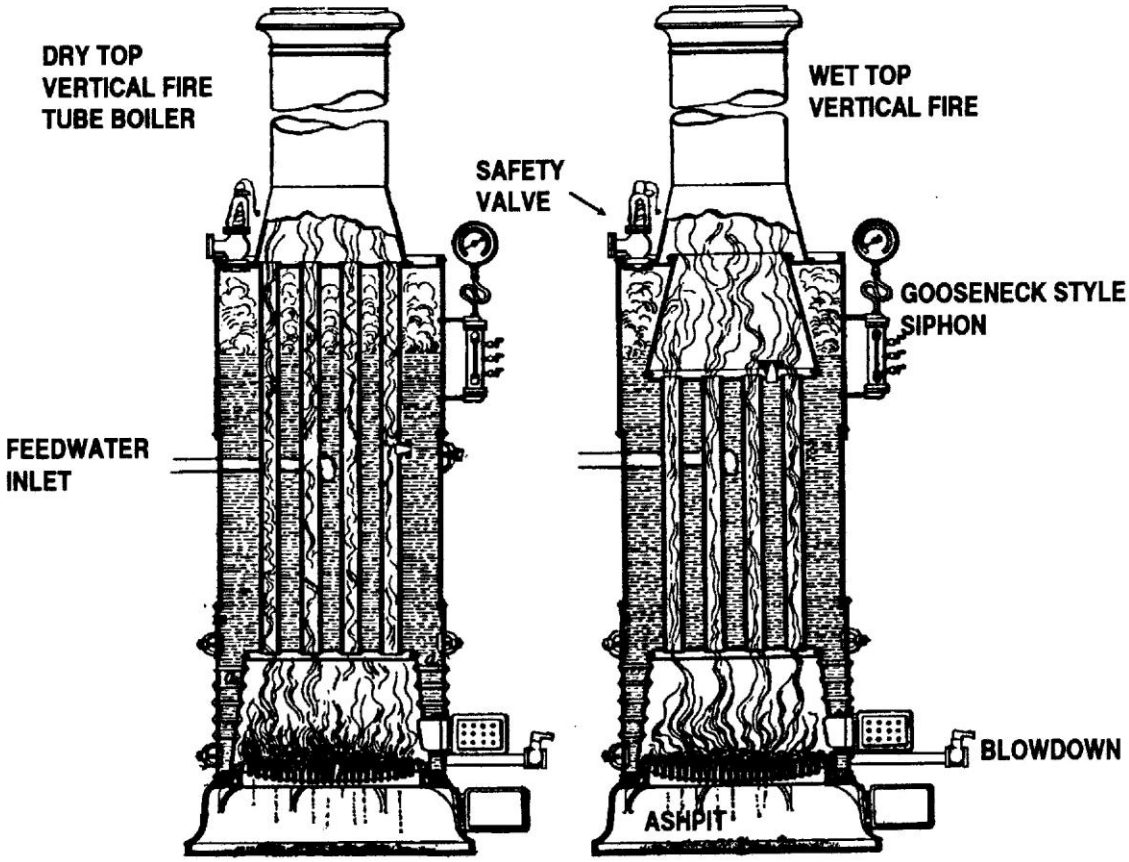
5. A 3/16 inch hole is drilled into the staybolt from the outside to a point 1/2 inch inside the outer shell so that if a staybolt does break, steam blowing through the hole will warn the Operator. This is called a tell-tale. Plugging the hole until the staybolt can be replaced is done by driving a tapered pine plug into it.



6. Flexible or Tate staybolts are used in an attempt to prevent the breaking of the staybolt

7. A lot of small staybolts spaced close together are better than a few large ones spaced far apart because if a small staybolt broke, it is not supporting as many square inches as the large staybolt and the other staybolts will handle the added stress better.

8. The boiler is supported by sitting on a cast iron base that forms the bottom of the ashpit, or the ashpit can be made of brick. Expansion is straight up.



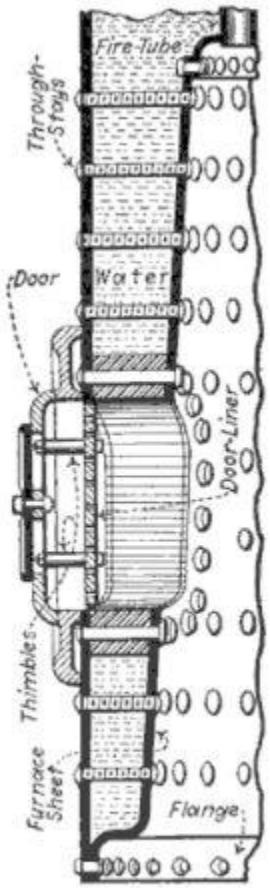
9. If the tubes in the boiler are less than 4 feet in length, the feedwater line cannot be less than 1/4 the length of the tube above the crown sheet. If the tubes are over 4 feet in length, then the lowest point for admitting feedwater is not less than 1 foot above the crown sheet. You cannot connect the feedwater line to the gage cock openings, the water column or the gauge glass.

10. Special care must be taken in firing the dry top vertical boiler because too hot of a fire on start up can damage the tubes before steam is formed. The steam cools the tubes and keeps them from burning. If the top of the crown sheet has scale build-up, the crown sheet can overheat and fail. If the boiler is fired too heavily, leaks can develop at the upper tube sheet.

11. The steam connection for the water column is tapped into the upper part of the shell and the water connection is tapped in at a point not less than 18 inches above the mud ring. The lowest safe water level is 1/3 the height of the tubes above the crown sheet.

12. At least three hand holes are located around the crown sheet so that the mud and scale that forms on the crown sheet can be removed. At least three hand holes are also located around the bottom of the boiler to allow removal of the sediment that settles there.

13. As you can see from the illustration, the crown sheet is made smaller than the tube sheet. The tube and crown sheet are thicker than the shell because of the thickness required to roll the tubes, and because the top tube sheet is exposed to corrosion from exhaust steam and rain.

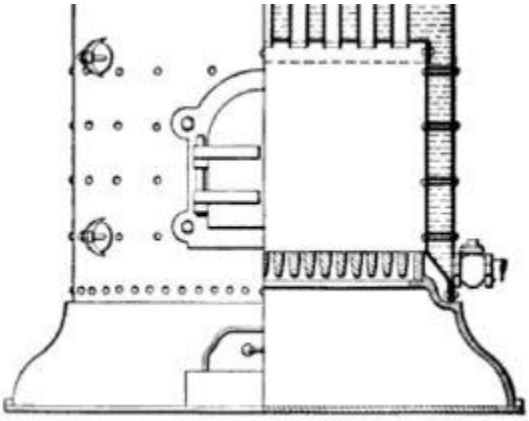


Furnace sheet flanged to close water-leg at bottom.

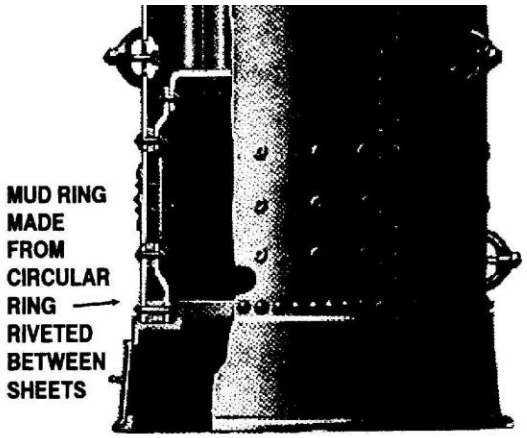
14. The Vertical fire tube boiler usually uses 2 inch tubes.

15. Sometimes the gauge glass and trycocks are mounted directly on the shell without a water column.

16. When firing at 100 per cent of rating, 12 square ft. of boiler surface equals one horsepower



17. The blowdown line is attached to the lowest part of the water leg. A reinforcing pad is located where the line attaches to the boiler to provide enough threads to properly screw in the pipe.



18. The mud ring is a steel or wrought iron ring shaped like a tire lying on its side that was cut along the centerline of the tread and the top half removed. It connects the shell and the furnace sheet at the bottom. Sometimes a chain is linked together in the bottom of the mud ring to help in cleaning by pulling the chain around.

ADVANTAGES OF THE VERTICAL FIRE TUBE BOILER

1. It is a rapid steamer.

2. It is economical

3. It is easily transported.

4. It does not take up much floor space.

DISADVANTAGES OF THE VERTICAL FIRE TUBE BOILER

1. Steam space is small. If the wet top boiler is fired heavily, the water will start priming.

2. It has poor water circulation

3. Heavy firing may damage the crown sheet.

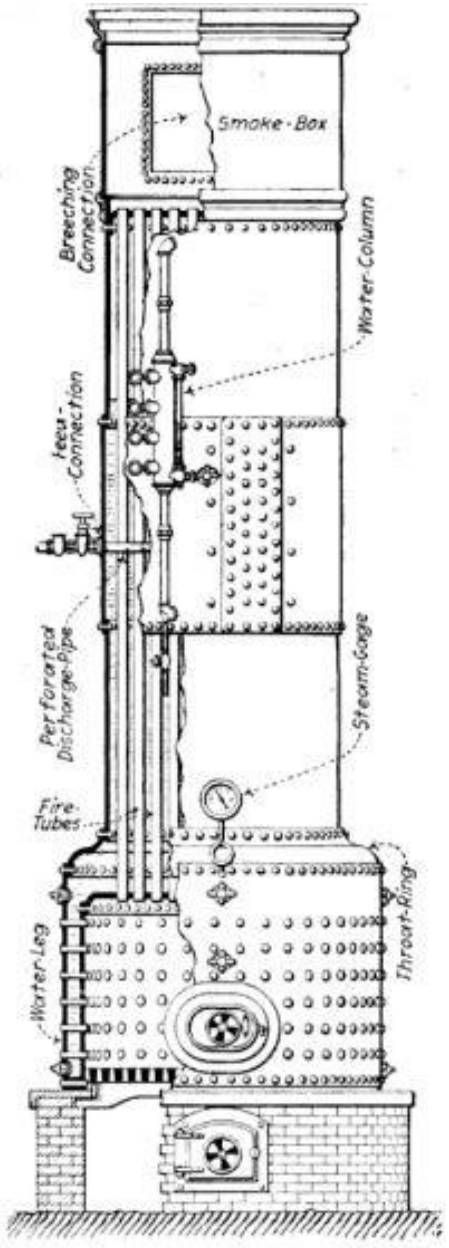
4. This is a one gas pass boiler and is therefore very wasteful of fuel.

5. Limited access to the water side makes cleaning difficult.

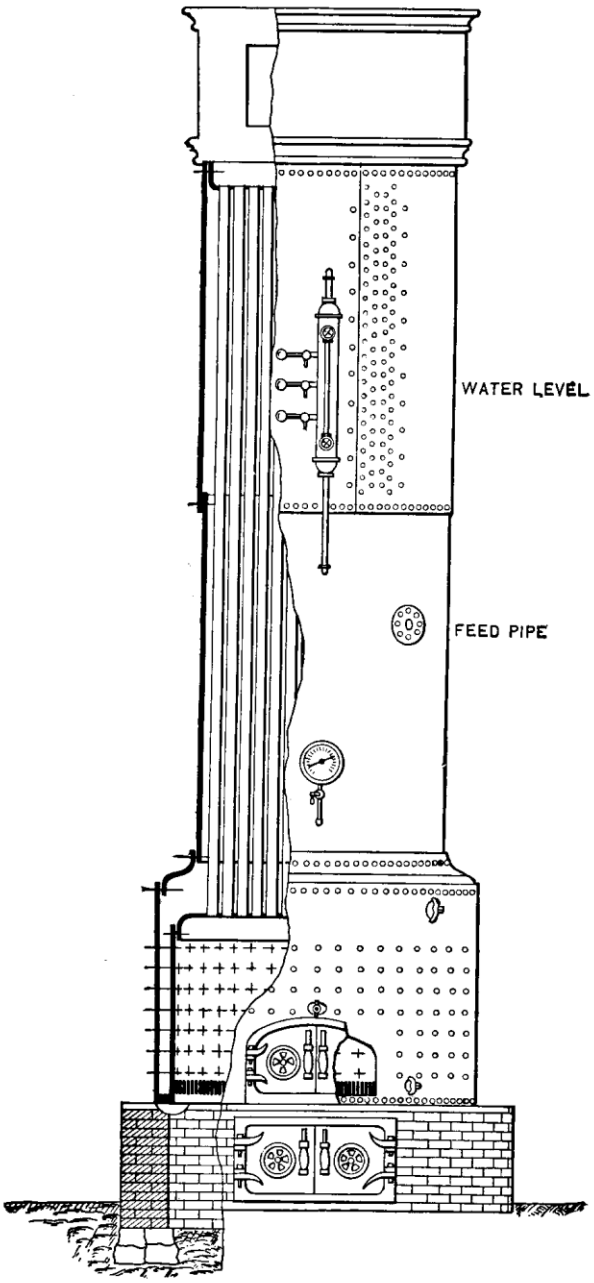
6. Corrosion of the shell inside the furnace is accelerated due to the ashes lying against the boiler steel.

7. Because of the small furnace, Vertical Fire Tube boilers are hard to keep from producing smoke when burning bituminous coal.

MANNING BOILER



Manning vertical fire-tube boiler.



The Manning boiler is a much larger version of the vertical fire tube boiler. It is used where little floor space is available for one of the other types of boilers, but a lot of headroom is available. The boiler sits on an ashpit which can be constructed of either brick or cast iron. The firebox is made larger than the one for the vertical fire tube boiler by increasing the size of the water legs. These larger diameter sheets are attached to the smaller one by an Ogee ring.

Important points to remember about the Manning boiler are:

1. The fusible plug is attached to an outer tube not less than 1/3 the way up from the lower tube sheet, opposite a handhole.

2. The water circulation is up over the crown sheet and down around the shell.

3. This is a one pass boiler. The flue gasses go straight up the tubes and out the stack at the top of the boiler.

4. The Manning sits on a cast iron base. The expansion is straight up.

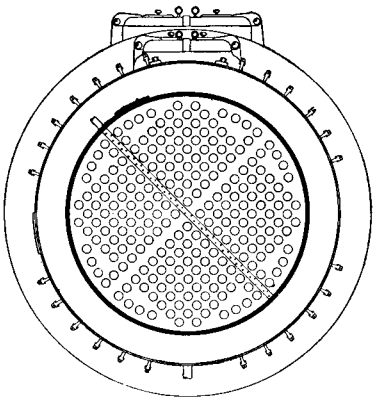
5. The feed line enters about 1/2 way up the boiler, extends between the tube bundles and is perforated to keep the cooler water from thermally "shocking" the boiler. The feedwater line cannot be connected less than 1 foot above the crown sheet.

6. The first place to overheat in case of low water will be the top tube sheet and the upper ends of the tubes. Steam does not have the same heat transfer capabilities as water and the steam will not protect the upper tube sheet and upper tube ends if the water level gets too low. If the water level falls below the crown sheet, the sheet will melt and a steam explosion is sure to result.

7. The steam connection of the water column is tapped into the upper part of the shell. The water connection is at least 6 inches below the lowest allowable water level but cannot be lower than 18 inches above the crown sheet. The lowest allowable water level is not less than 1/3 the height of the tubes above the crown sheet. The middle of the gauge glass is at 2/3 the height of the tubes.

8. At least three handholes are required around the crown sheet and another three handholes are required around the bottom of the boiler for cleaning.

9. Two blowdown lines are usually provided on larger sizes.

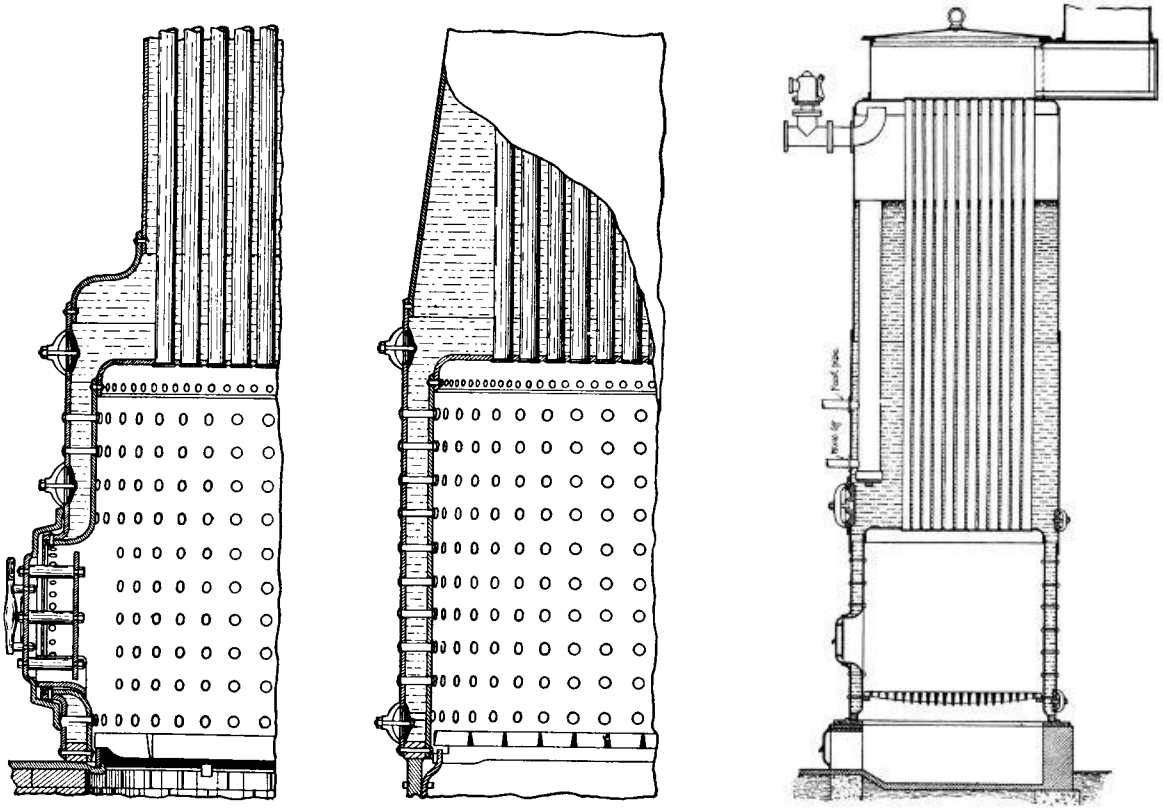


10. Tubes are usually 2 and 1/2 inches in diameter. They are "nested" in four bundles to aid in cleaning. The tube bundle on the right shows the feedwater line.

11. Due to its height, the try cocks are operated by chains.

12. The pipe that connects the steam gauge is brought down from the steam space to the Operator level. The water in the gauge line will make the gauge read 1 psi higher than actual for every 2.31 feet of water that is in the pipe. This must be compensated for by adjusting the pointer on the gauge.

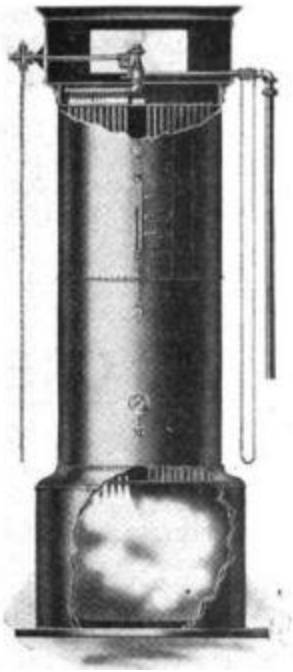
13. The safety valve and steam outlet are attached to the upper part of the shell by riveting or fusion welding.



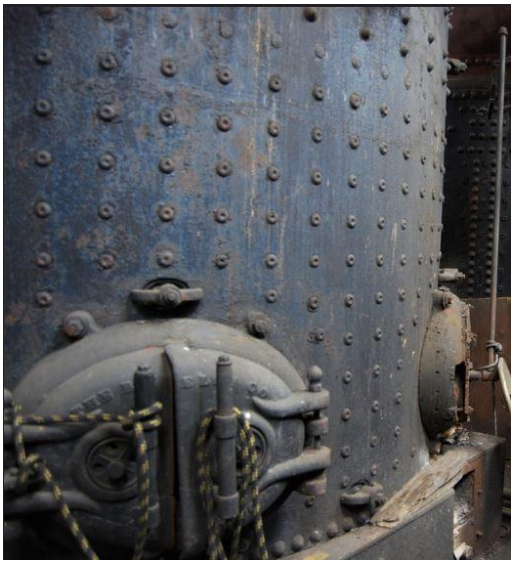
14. The S-shaped Ogee connects the furnace sheet to the tube sheet. The Ogee ring is a source of weakness. If a crack at the Ogee ring extends more than 3 inches, the boiler cannot be used until the Ogee ring is replaced. Some Manning type boilers use a tapered course of steel to eliminate the Ogee ring. Another method of overcoming the weakness of the Ogee ring is to extend the outside sheet straight up to the breeching.

15. The maximum allowable working pressure on the Manning can be as high as 200 psi.

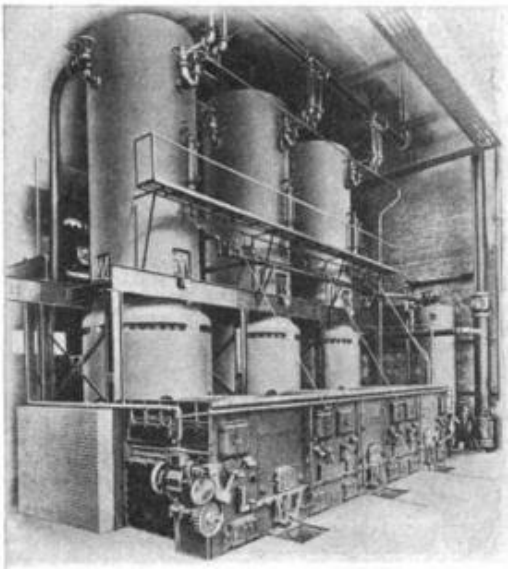
16. The riveted seam at the bottom of the waterleg should have a ring of firebrick between the seam and the furnace to protect the seam from the fire.



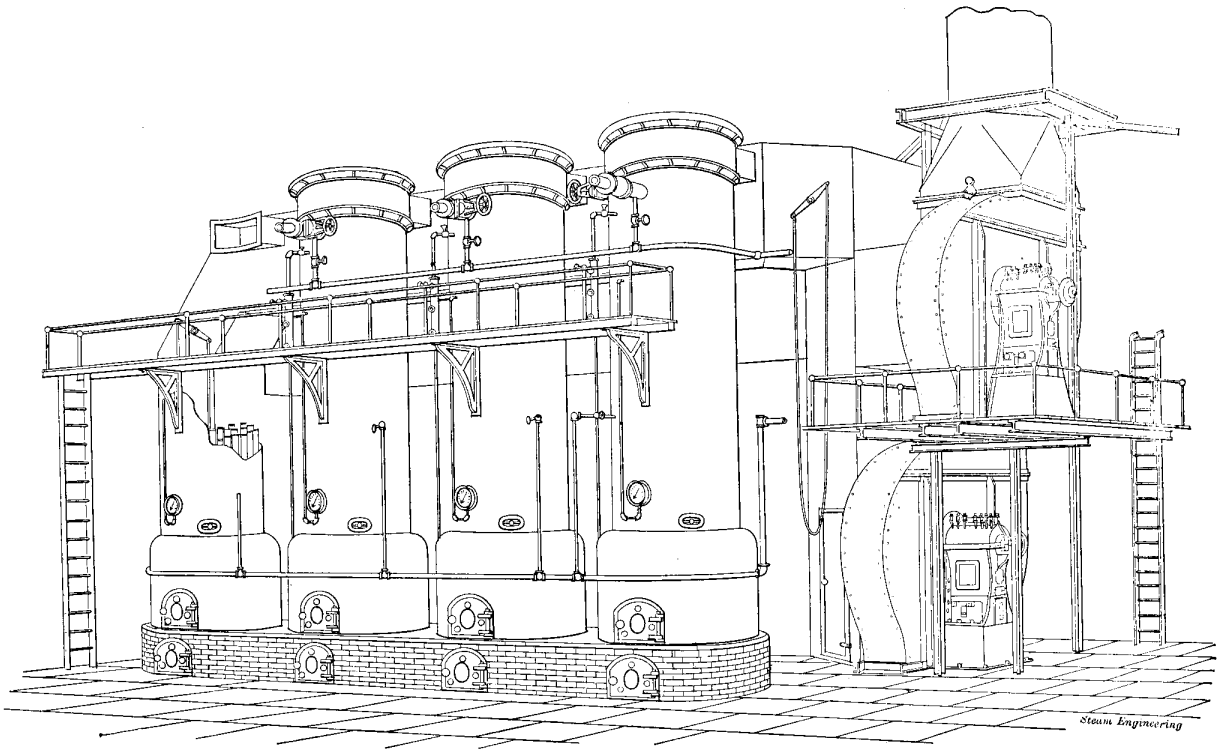
Manning Boiler with sootblowers



Manning Firing Door

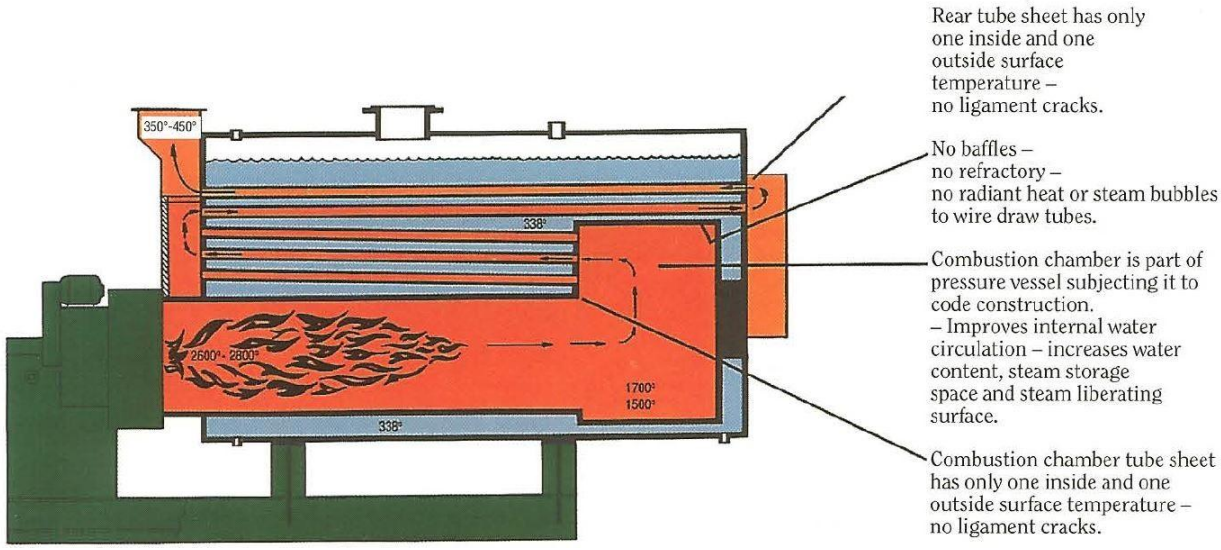


Three Manning Boilers in Battery with Mechanical Stokers

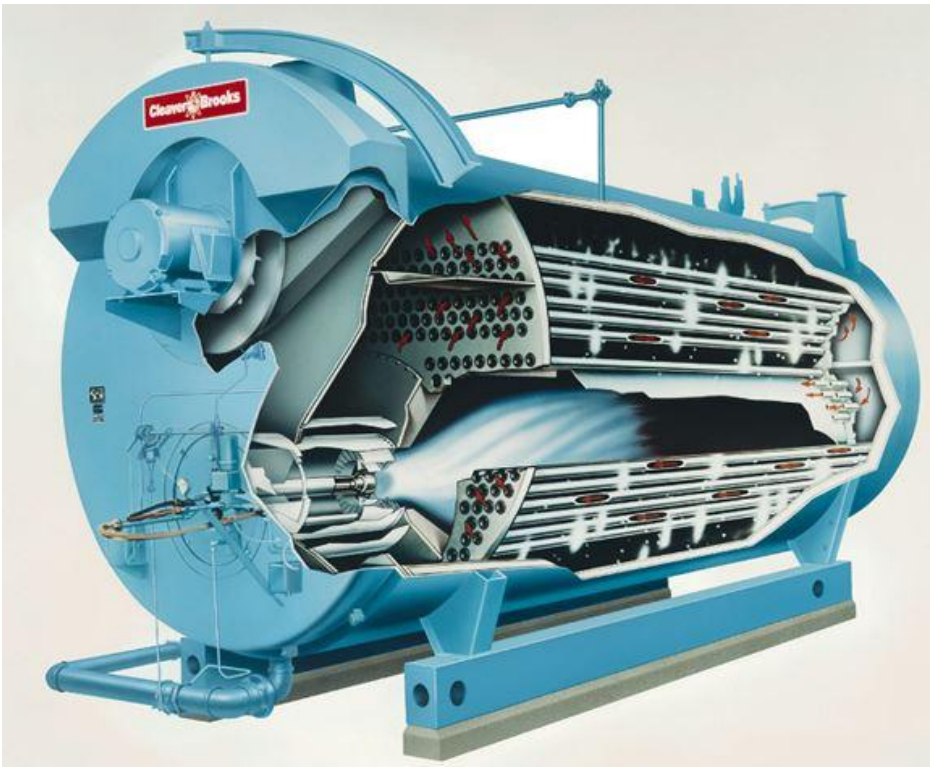


Four Manning boilers in Battery with forced and induced draft fans

SCOTCH MARINE BOILERS

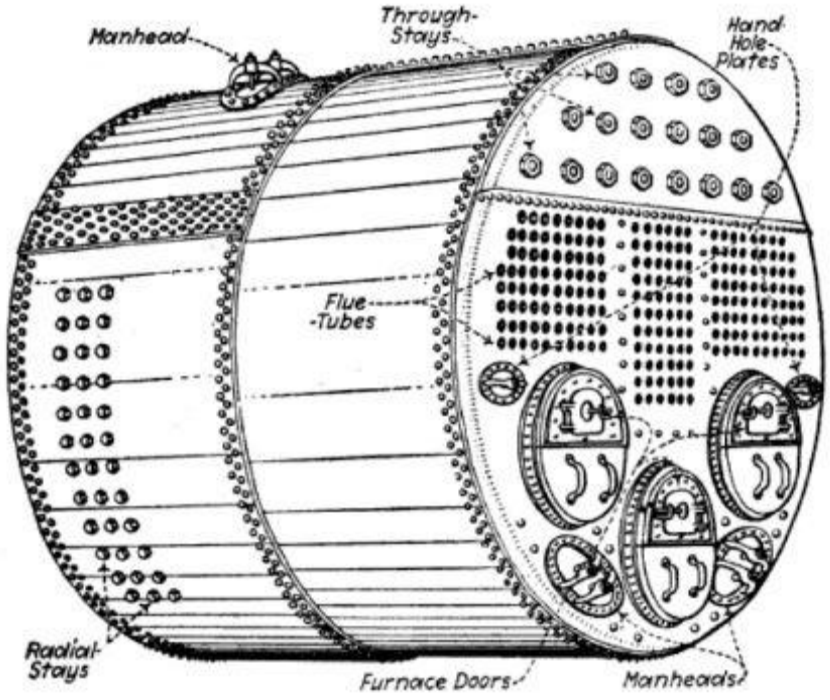

Rear tube sheet has only one inside and one outside surface temperature – no ligament cracks.
No baffles – no refractory – no radiant heat or steam bubbles to wire draw tubes.
Combustion chamber is part of pressure vessel subjecting it to code construction. – Improves internal water circulation – increases water content, steam storage space and steam liberating surface.
Combustion chamber tube sheet has only one inside and one outside surface temperature – no ligament cracks.
350°-450°
338°
2600°-2800°
1700°
1500°
338°

Johnston Wet Back Scotch Marine Boiler



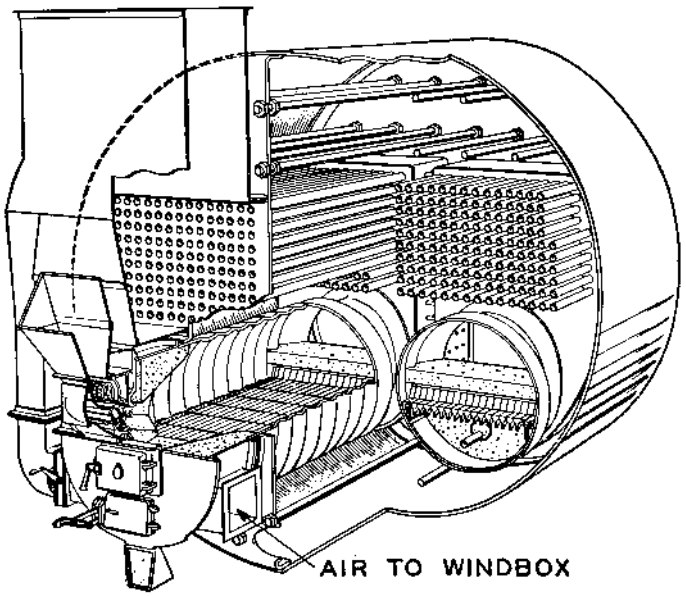
Cleaver Brooks Dry Back Scotch Marine Boiler

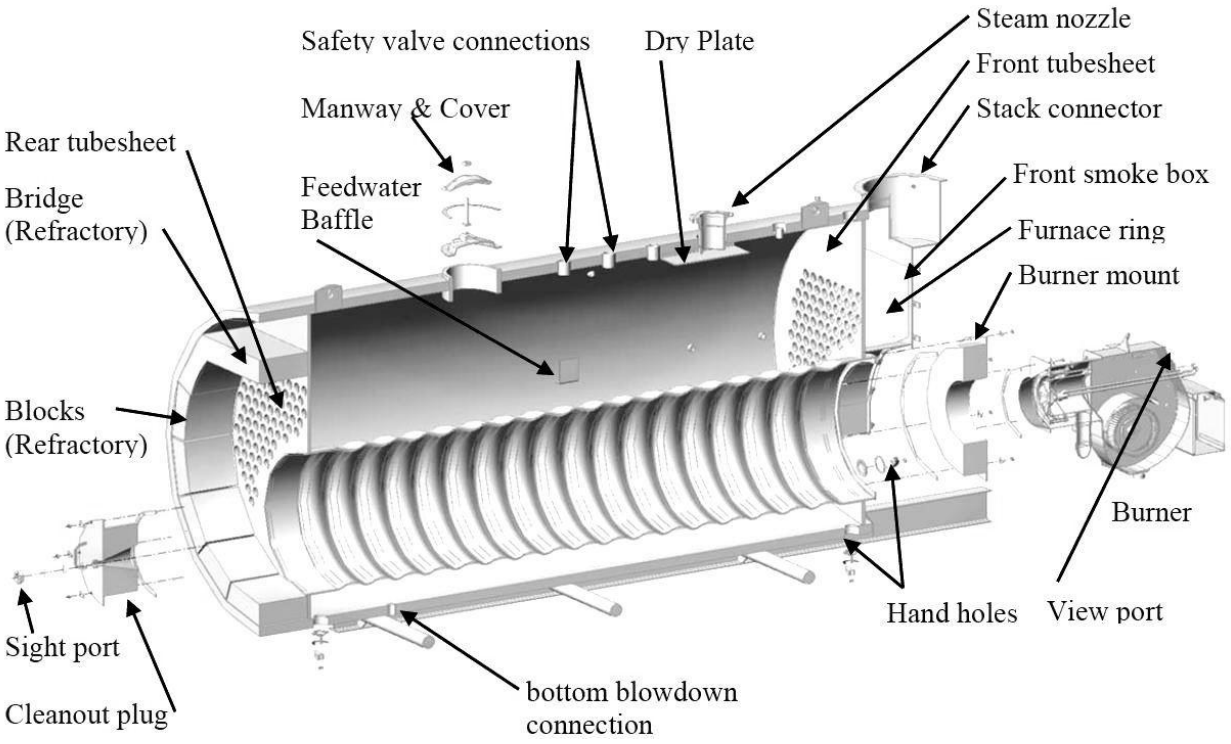
There are two types of Scotch Marine boilers, the dry back and the wet back.



External view of typical Scotch boiler.

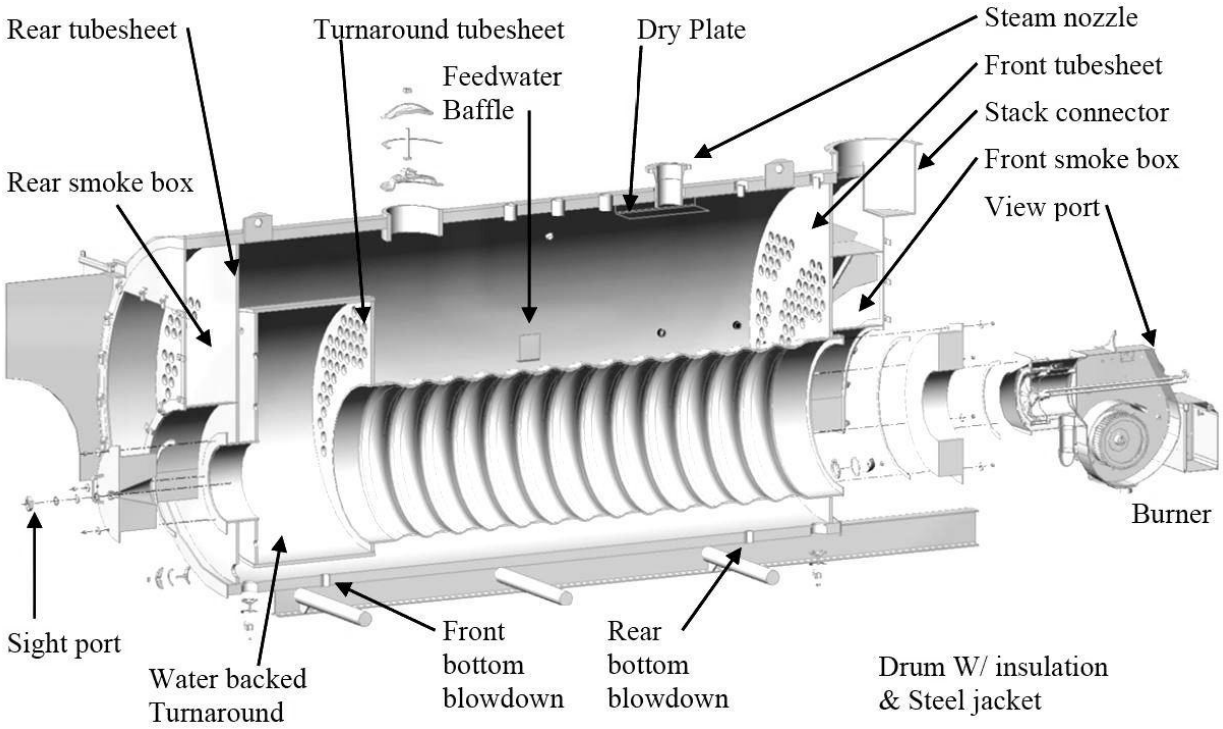
The wet back is the original type that was popular in marine vessels. It was developed to produce the highest amount of steam possible in a compact space to fulfill the requirements of ships. The original wet back is noted for having shells that are bigger in diameter than they are long. The diameters of the original wet back Scotch Marine range from 10 to 20 feet. The lengths range from 7 to 11 feet. From two to four furnaces of large diameter and short length are used in the original wet back Scotch Marine. The large flat surfaces of the furnace end and the front and back sheets require a large amount of stays.





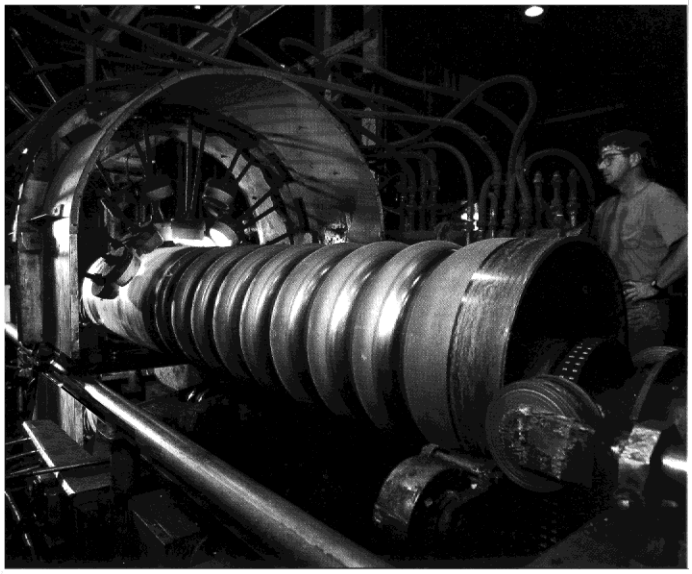
Dryback Superior Boiler

The modern dry back Scotch Marine and wet back Scotch Marine boilers are very common in modern small to medium size plants. They only have one furnace and they are greater in length than diameter. The modern Scotch Marine boiler can have from 2 to 5 gas passes. The ability of the modern dry back or wet back Scotch Marine boiler to be shipped complete to the jobsite with only electrical, fuel, and water hook-up needed saves installation costs.

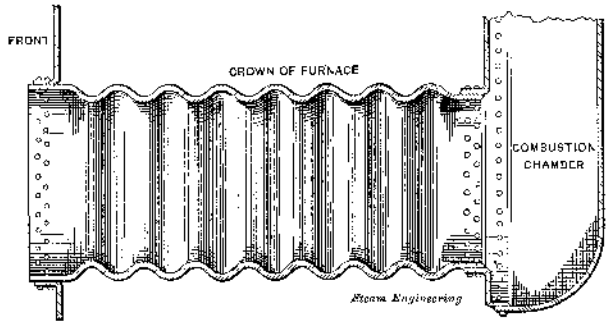


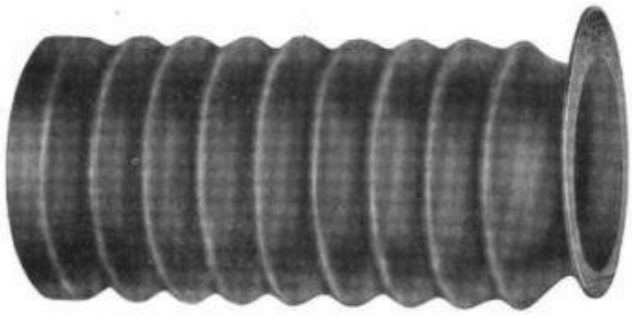
Wetback Superior Boiler

FURNACE CONSTRUCTION of SCOTCH MARINE BOILERS

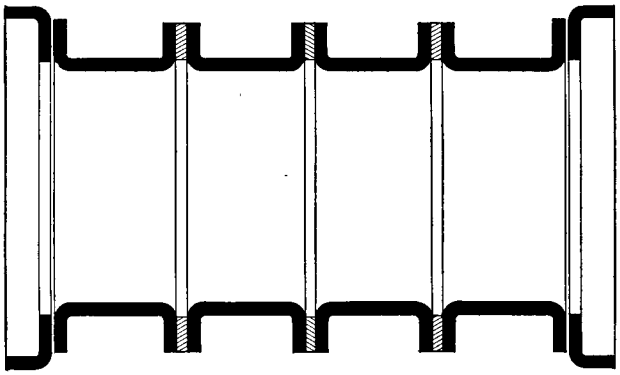


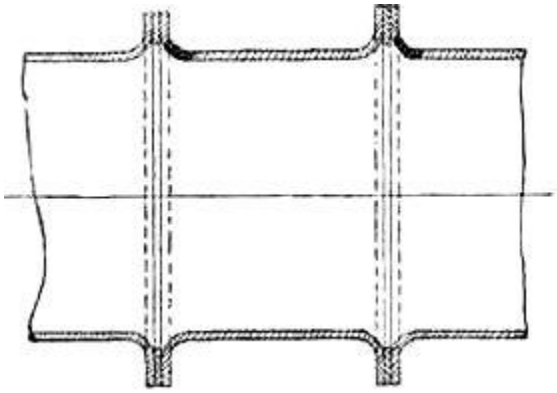
The corrugated furnace, sometimes called a Morison Furnace is commonly used in modern Scotch Marine boilers. A long plain furnace flue is heated with open wide flame torches and rotated while rollers indent the furnace flue. This creates a sturdy, leak-free furnace with an extended surface for better heat transfer.





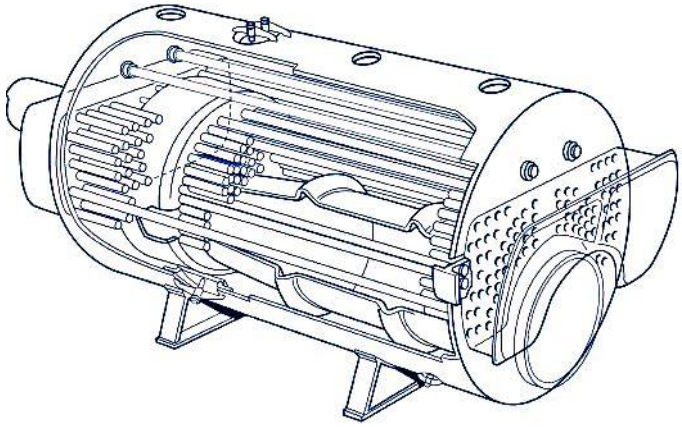
The end of a corrugated furnace can sometimes end in a flange for attaching it to the combustion chamber. An inward facing flange to allow removal of the furnace from the boiler is called a "Horse's Collar"



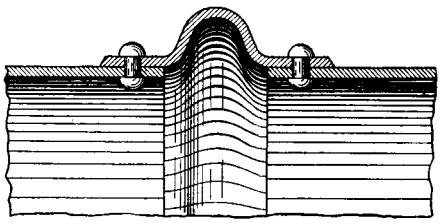


The Adamson Ring Furnace is a series of short sections of flanged furnace, riveted together with reinforcing rings to create a long furnace. Each flange is a potential source of leakage.

Bowling Hoop furnace above and inside the Scotch Marine Boiler on the right

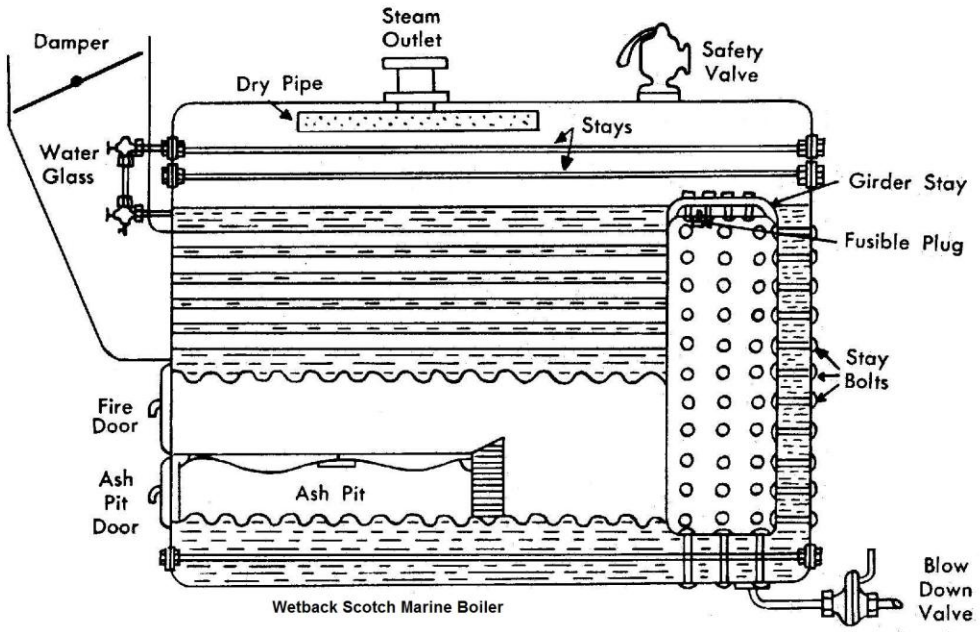


11. Because the furnaces of the Scotch Marine are large, they use special means of stiffening the furnace. The methods are:



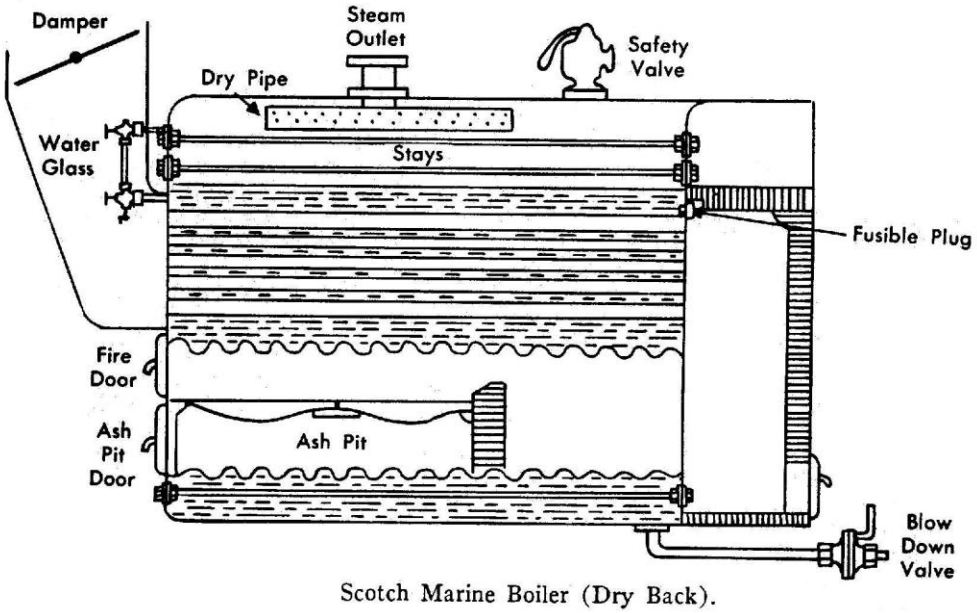
A. by corrugating (Morison Furnace)
B. by dividing the furnace into sections with flanges (Adamson Ring)
C. by welding stiffening rings around the furnace
D. by using staybolts between the furnace and the outer shell.
E.The Bowling Hoop is another way to strengthen a furnace by riveting, rolling, or welding rings at intervals.

Important points to remember about the Scotch Marine boiler are:



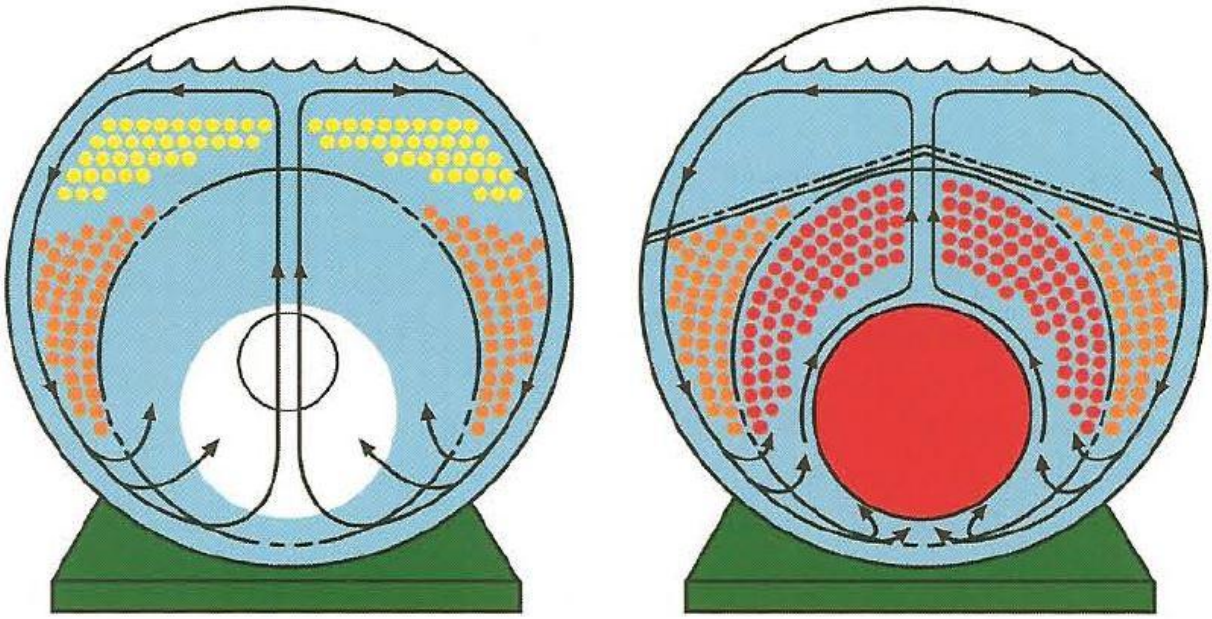
Wetback Scotch Marine Boiler

1. The fusible plug on the wet back Scotch Marine Boiler is on the top of the crown sheet and projects through the sheet not less than one inch.



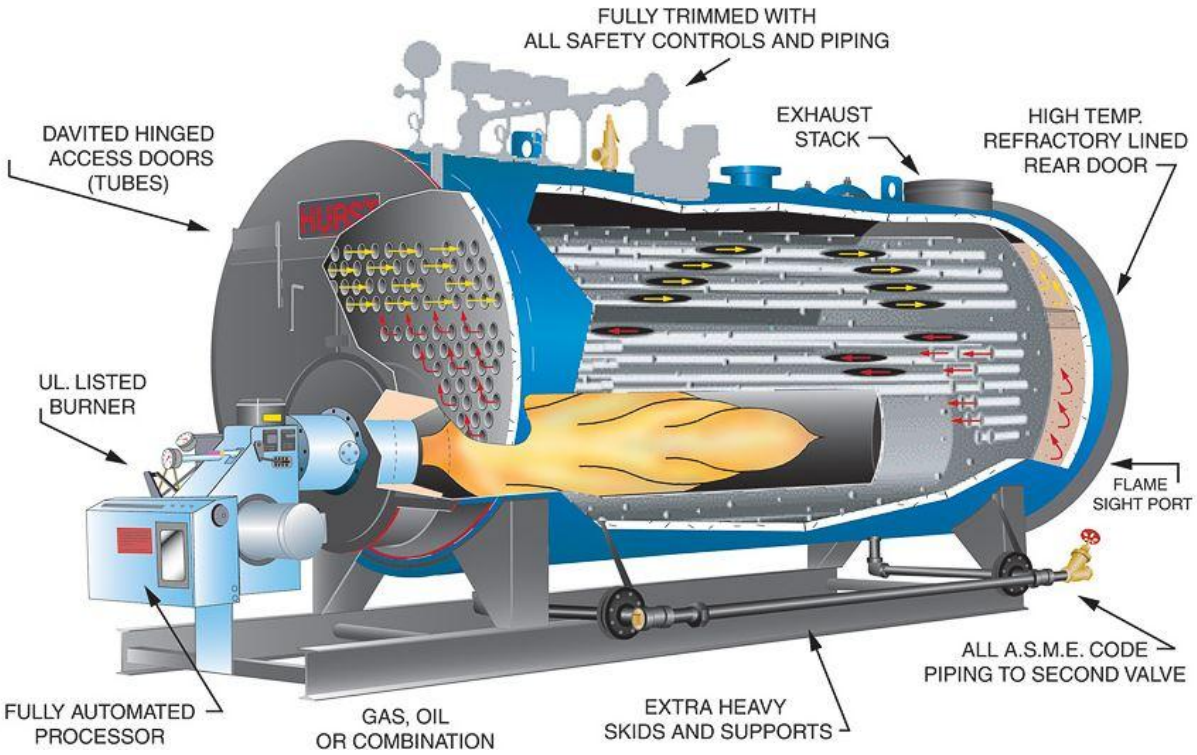
Scotch Marine Boiler (Dry Back).

2.. The fusible plug on the dry back Scotch Marine Boiler is located in the rear head not less than two inches above the top row of tubes and projecting through the sheet not less than one inch. The only exception to this is when the distance from the top of the tubes to the top of the shell is 13 inches or less, but the plug can never be lower than the top row of tubes.



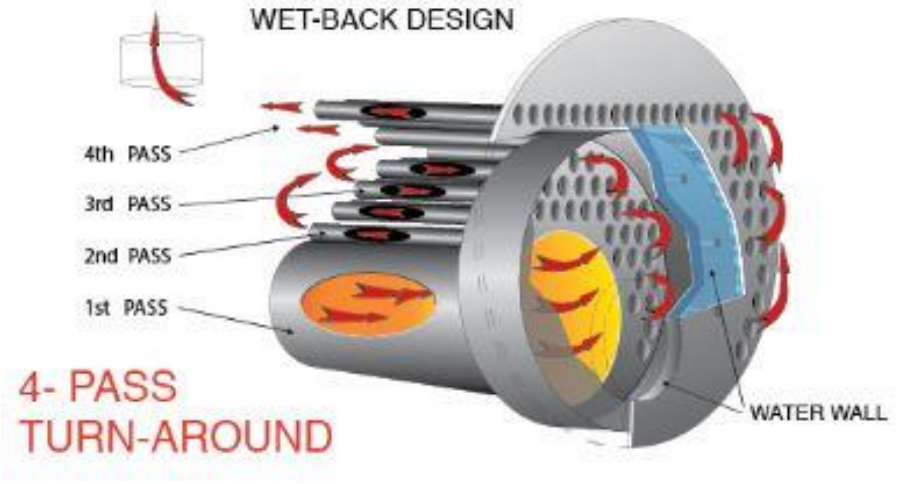
Water Circulation in Scotch Marine (Courtesy Johnston Boilers)

3. The water circulation is up over the combustion chamber and down along the sides of the shell.



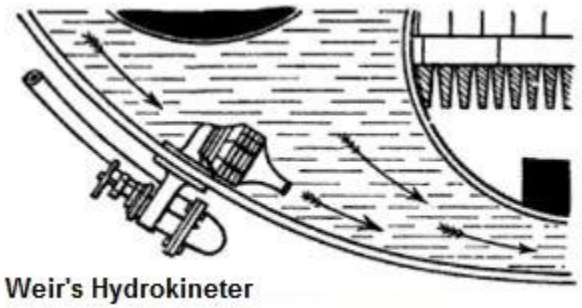
Three Pass Scotch Marine (Courtesy Hurst Boilers)

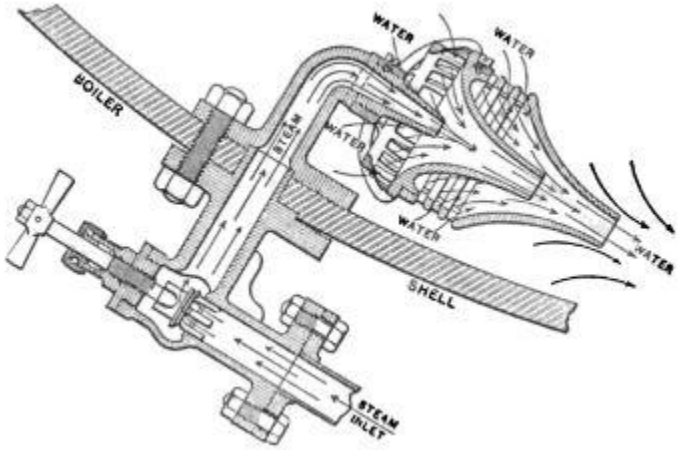
4. The Scotch Marine is supported on cradles or I beams mounted to the floor.



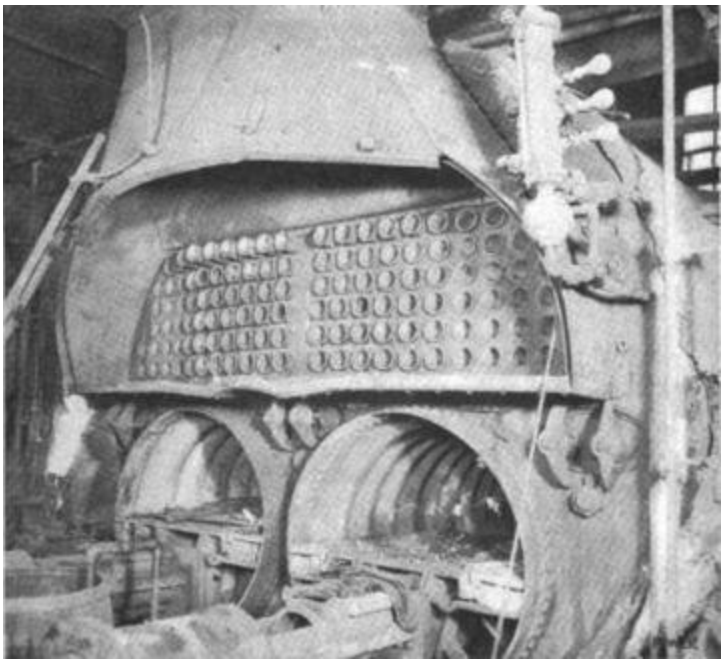
Four Pass Scotch Marine (Courtesy Hurst Boilers)

5. This is a two gas pass boiler in the original wet back configuration. The flue gasses pass through the furnace to the combustion chamber, reverse and come back through the tubes above the furnace to the front of the boiler and out the stack. Modern Scotch Marine boilers have from two gas passes to five gas passes.





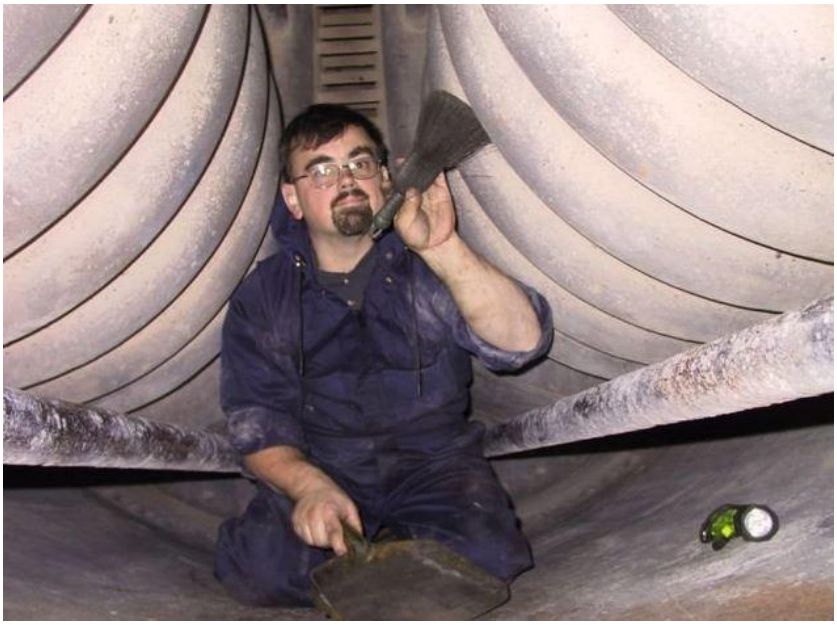
6. The feedwater can discharge in two places. It can go through the side of the boiler near the front tube sheet and discharge just above the tubes but below the water level, or it can discharge down below the furnace flue. The reason for discharging below the flue is to increase water circulation. The water tends to remain stagnant below the flue. The disadvantage is that if the feed line breaks between the check valve and the boiler, all the water will be forced out of the boiler. A device to increase circulation in the stagnant water area under the furnaces is called a "Hydrokineter". It uses steam through a nozzle and injector cones to heat and start the circulation of the water below the furnace. They are obsolete but some Examiners still ask questions about it.



7. The first place to overheat in the event of low water would be the crown sheet in the combustion chamber. This is a picture of a 1912 boiler explosion due to a collapsed crown sheet at Mt. Clemens Sugar Company in Southeast Michigan.

Another danger spot for overheating is the top of the furnace flue; scale can build up on top of the flue and then poor heat transfer will cause the furnace flue to overheat and collapse. The lowest safe water level is 3 inches above the crown sheet.

8. The water column is mounted on the side of the boiler to allow the doors to swing open for cleaning. The steam connection is at the top of the boiler and the water connection is in the lower 1/3 of the shell.



Inspection of the corrugated furnace though the bottom manhole. Note the through rods on either side of the Operator.

Inside the top manhole of the Scotch Marine Boiler

9. If the boiler is over 48" in diameter, the Code requires a manhole above the tubes. Two manholes in the front of the boiler, one above the tubes and one below are recommended to provide access below the furnace.

10. The blowdown line can be connected at the front or rear of the boiler or in both locations.

11. The Scotch Marine can be fired by gas, oil, or coal. When the boiler is fired by coal, a firing grate and a bridge wall are installed. Coal fired boilers can either be hand fired or use a spreader stoker.

12. The lowest safe water level is three inches above the crown sheet.

13. The Scotch Marine is similar to the locomotive boiler because they both use crown sheets in construction of the furnace.

ADVANTAGES OF THE SCOTCH MARINE BOILER

1. It is compact and no setting foundation is required.

2. It does not require high ceilings.

3. The tubes are all the same size and length, so that spare tubes are easy to stock and install.

4. Some dry back Scotch Marine boilers have circular end caps on hinges on the front and back of the tube sheets that allow easy cleaning of the fire side of the tubes and replacement of refractory.

DISADVANTAGES OF THE SCOTCH MARINE BOILER

1. If fired too heavily with a coal or oil, the boiler may smoke due to incomplete combustion, caused by the fixed size of the furnace.

2. Water circulation is sluggish below the furnace.

3. Access to the water side of the tubes is difficult for cleaning.

4. The large number of stays in the original wet back Scotch Marine boiler are a source of weakness.

5. When the rear door is swung on a davit, care must be taken to ensure the door refractory baffle does not contact the boiler, damaging the refractory.

6. The rear end of the dry back combustion chamber requires a lot of maintenance due to the temperature differentials and cracking of the refractory

Chapter 5 Questions

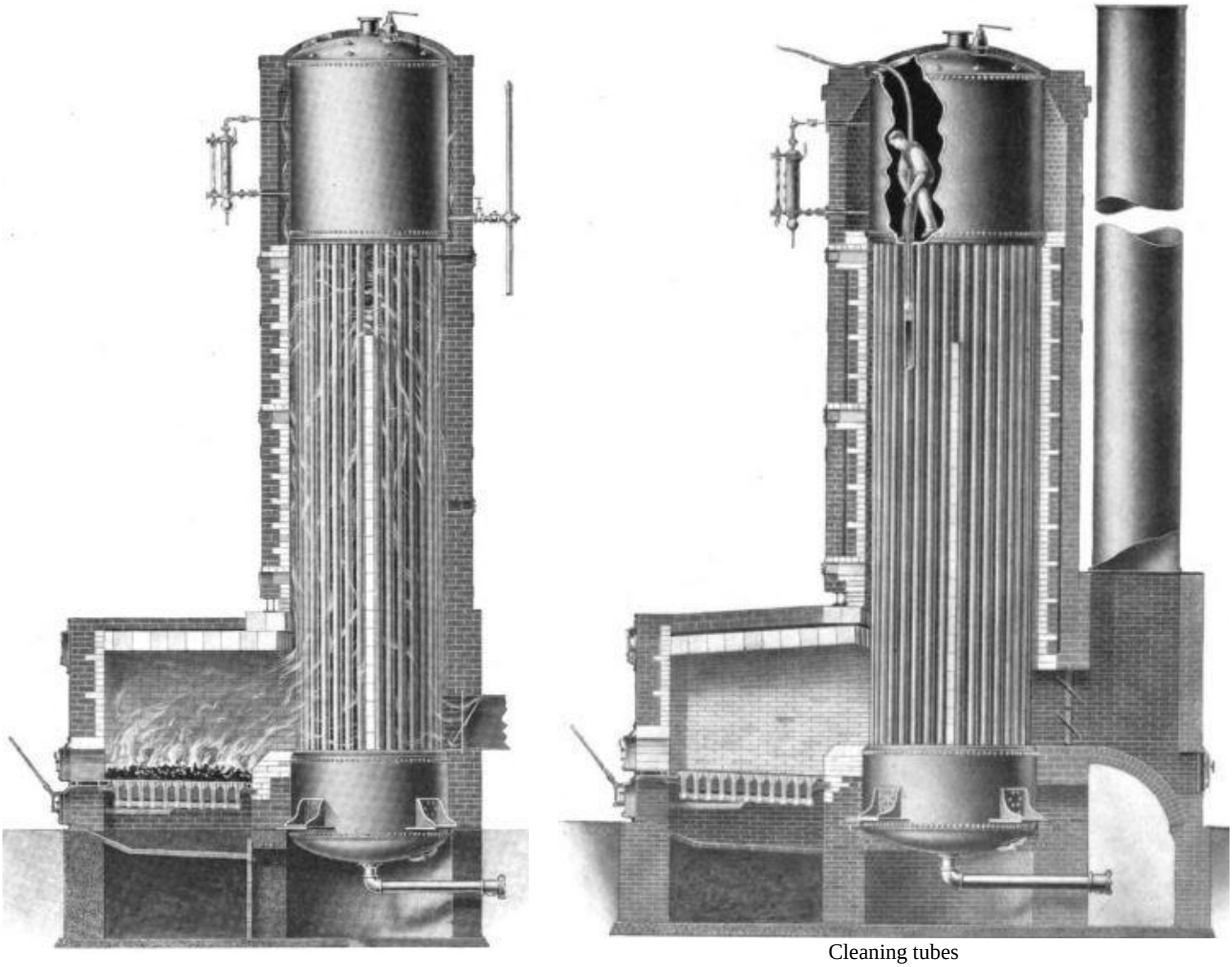
1. Where is the fusible plug located in the HRT? The vertical dry top, vertical wet top, Scotch marine, Locomotive Boiler.
2. Why is the HRT the only boiler that needs a V wall to protect the blowdown line?
3. What are the maximum shell diameter and pressure for the HRT? Why?
4. Why don't they use diagonal stays below the tubes?
5. What is the difference between a through stay and a through-to-head stay?
6. When does the Code require 2 manholes?
7. Where is the combustion chamber and flame bed in an HRT?
8. Name some uses of the vertical boiler.
9. Where does the feed line enter the vertical boiler? Does it discharge water at the shell?
10. Where does the Code prevent you from attaching the feedwater line on the vertical boiler?
11. Which is smaller, the crown sheet or the tube sheet of the vertical firetube boiler?
12. How far inside the outer shell must the hole in the stay bolt extend?
13. What happens if a large fire is generated in the vertical fire tube boiler on startup?
14. What is the objection to the ogee ring in the manning boiler? How is it taken care of?
15. What types of furnace construction are used with the scotch marine boiler?
16. What is the "horses collar"?
17. Why does the feedwater line sometimes discharge below the furnace?
18. What is the first place to overheat in the Scotch Marine boiler?
19. How do you clean the tubes in the Scotch Marine boiler?
20. Why will the Scotch Marine boiler have a tendency to smoke when burning oil or coal?
21. Where does the feedwater enter the locomotive boiler?
22. What is a thermo-siphon arch?
23. How are the HRT and the locomotive boiler similar?

Refurbished rear door (Courtesy Industrial Boiler and Mechanical)

Chapter 6

WATER TUBE BOILERS

WICKES VERTICAL WATER TUBE BOILER



Cleaning tubes

The Wickes vertical water tube boiler consists of an upper and lower drum joined by straight tubes about 22 feet in length and 4 inches in diameter. The top drum is the steam and water drum that provides the disengaging surface for the steam to separate from the water. The connections for the steam outlet, safety valve, manhole, feed pipe, and water column are on the top drum. The bottom drum also has a manhole as well as the blowdown lines and the brackets that support the boiler on its foundation. This boiler was manufactured by the Wickes Boiler Co. of Saginaw MI. which was purchased by Combustion Engineering which in turn was purchased by Asea Brown Boveri or ABB.

Important points to remember about the Wickes vertical water tube boiler are:

1. The fusible plug is located in the top drum, not less than 6 inches above the tube sheet and projecting through the sheet not less than one inch. It must be in the front of the boiler and exposed to the products of combustion in the first gas pass.

2. The water circulation is up the front rows of tubes closest to the furnace and down the back rows of tubes on the other side of the tile partition that creates the gas passes.

3. This is a 2 gas pass boiler. A tile baffle is placed between the tubes, from the top of the bottom tube sheet to about 3/4 the way up the tubes through the center of the nest of tubes. The combustion gasses pass up the tubes, over the tile baffle, and down the outlet to the chimney.

4. Since the lugs attached to the bottom drum sit on steel foundation plates anchored in concrete, the expansion is straight up.

5. The feedwater pipe enters the top drum near the back row of tubes and the cooler water descends into the mud drum. As the feedwater heats, the scale drops out into the mud drum.

6. The first place to overheat in case of low water would be the upper tube sheet.

7. The water column is attached at the top about 6 feet above the upper tube sheet in the top drum and at the bottom about 2 feet above the upper tube sheet in the top drum.

9. Manholes are located in both the upper and lower drums. Hand holes are located around the top of the upper drum to allow replacement of the tubes.

10. The blowdown line is in the center of the bottom drum. The bottom drum is dished so that all sediment settles toward the center.

11. The top drum is large enough for a man to stand upright and allows easier cleaning of the tubes.

12. There are vertical internal braces in the top drum of the crowsfoot design that allow access to the tubes while stiffening the upper drum.

13. The boiler is completely surrounded by masonry except on the very top.

14. This boiler uses an external brick furnace known as a Dutch oven.

ADVANTAGES OF THE WICKES VERTICAL WATER TUBE BOILER

This boiler embodies nearly all the design features of the perfect boiler.

1. The steam space is high and large and can carry overloads without priming.

2. The tubes are easy to clean and the boiler is easy to repair.

3. The mud drum is ample and designed for sediment collection and removal.

4. The gas path sets up a natural circulation of water in the boiler with no "dead spots".

5. The rupture of one tube will not lead to catastrophic failure of the boiler.

6. No seams are exposed to the direct action of the fire.

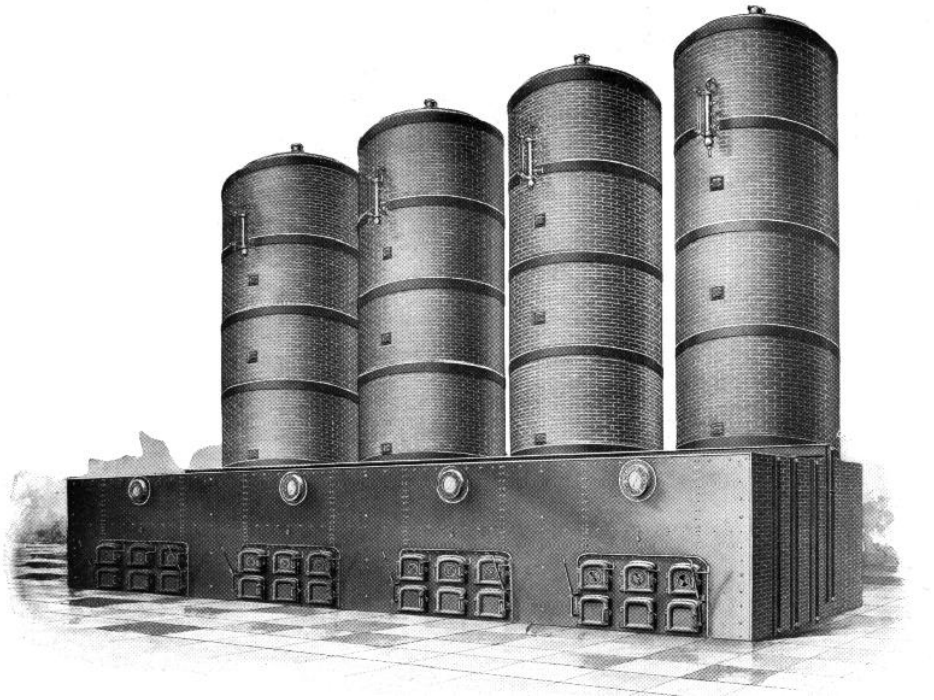
7. It generates a large amount of steam in relation to the floor space it requires.

8. The boiler is free to expand without placing stress on the brickwork.

9. The boiler is easy to construct.

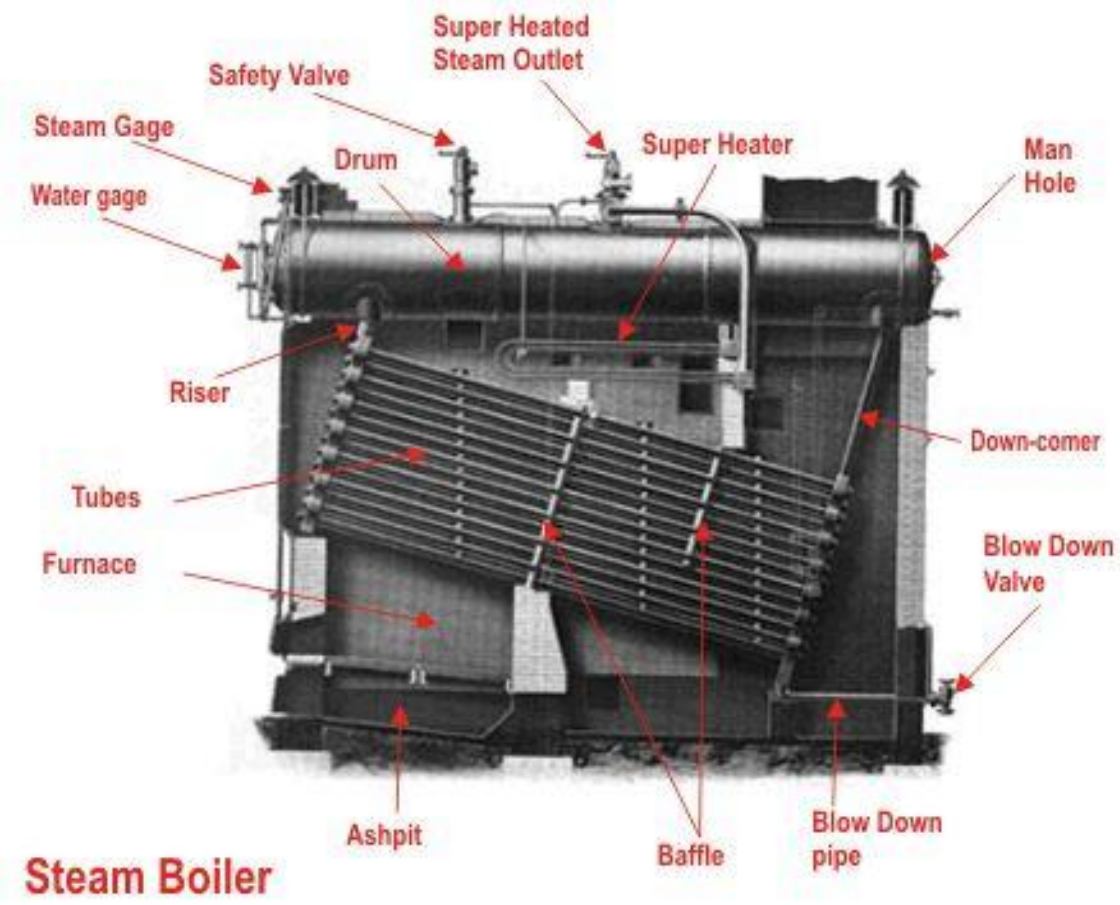
10. Since it uses the Dutch oven, the furnace can be easily sized for the maximum efficiency of the fuel to be burned.

So why didn't this boiler enjoy widespread success? The Dutch oven wastes fuel by heating refractory and brickwork that do not produce steam. If waterwalls had been placed in the Dutch oven to reduce refractory maintenance and produce more steam, this boiler might have been a greater success.



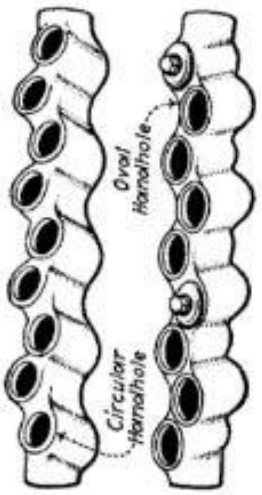
Battery of Wickes Vertical Watertube Boilers

BABCOCK AND WILCOX LONGITUDINAL DRUM BOILER

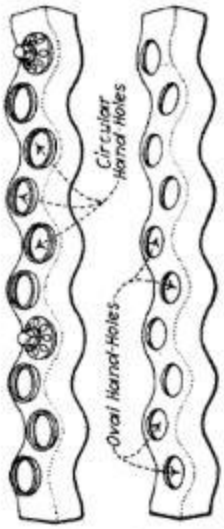


Steven Wilcox's water tube boiler was invented in 1856. This boiler incorporated the general features of previous water tube boilers but was vastly superior in both design and operation. The water leg extends entirely around the firebox. A nest of water tubes, which had a downward inclination, traversed the firebox from the front to the rear. The crown sheet of the firebox was braced with sling stays which were secured to the semi cylindrical top sheet. The inner and outer sheets of the water leg were tied together with staybolts. From this elementary design evolved the various classes of modern water tube boilers which have inclined tubes that connect front and rear headers or legs

The Babcock and Wilcox sectional water tube boiler of early form was built around 1870. In it were represented the essential construction principles which were developed and refined in the later designs. The tubes were of wrought iron. The vertical header sections were of cast iron. The two joined together, in the foundry, by laying the tubes in the mold and casting on the headers. A vertical baffle was erected midway, causing the gases of combustion to make two passes through the nest of tubes. The external wall of the setting was built to form a connection to the chimney.



Cast iron headers with elliptical and circular handholes.



Wrought steel headers with elliptical and circular handholes.

Shortly after 1877, George Babcock and Stephen Wilcox developed their longitudinal boiler with sinuous headers, also known as serpentine headers. This was one of the first commercially successful high pressure boilers, capable of from 100 to 170 psi in that era. The B&W longitudinal and cross drum, and the Heine are known as horizontal water tube boilers. The width of the grate determines how many rows of tubes are needed in these types of boilers.

Important points to remember about the B & W longitudinal boiler are:

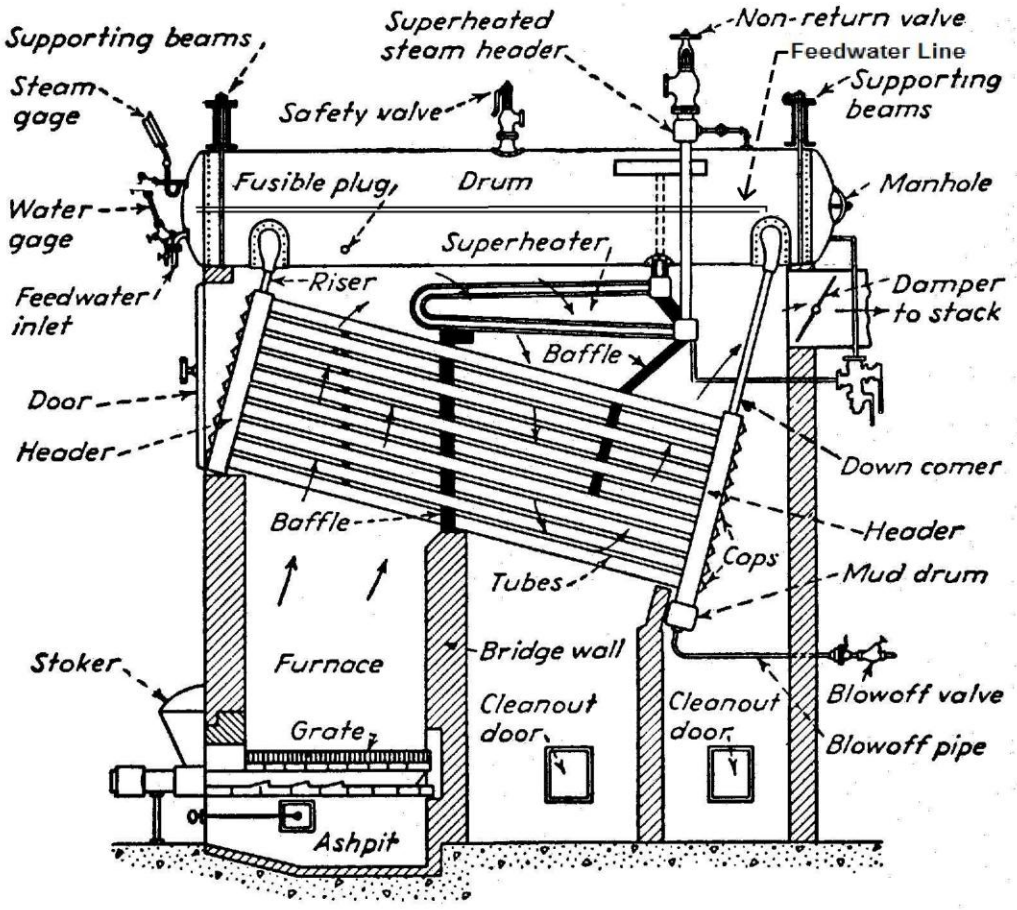
1. The fusible plug is located toward the front of the drum, 6 inches from the bottom of the drum, over the first pass of the products of combustion, and projecting through the sheet not less than one inch.

2. The water circulation is down the sinuous headers at the rear of the boiler, up through the inclined tubes to the front of the boiler, and across the drum to the rear. Inside the drum at the front is a curved plate that directs the water toward the back and helps prevent the rising steam bubbles from forcing water into the dry pipe.

3. This boiler has three gas passes. There is a baffle that can extend upward from the bridge wall to about 1/2 the length of the boiler. Another baffle extends downward about 2/3 of the way from the front of the boiler.

4. The baffles are made of firebrick which has been cast to fit between the tubes. Sometimes plywood forms are used and liquid refractory material is poured into the forms to mold to the tubes. After the refractory has dried, the plywood is burned out on the first usage of the boiler.

5. The drum is supported by saddles from overhanging I-beams. The boiler is free to expand or contract without damaging the brickwork.



6. The feedwater pipe enters the front of the boiler below the normal water level and travels to the rear of the drum before discharging. This allows some preheating to occur and also the water travels in the same direction as the circulation path.

7. The first place to overheat in case of low water would be the bottom of the steam drum at the front of the boiler.

8. The water column is attached to the front drum of the boiler with the steam connection at the top of the drum and the water connection at the lower part of the drum.

9. Manholes are located in the front and the rear of the steam drum.

10. A handhole is located on the opposite side of the header of each tube or group of tubes to allow access to the tube for inspection, cleaning, removal and replacement. The tubes are normally 4 inches in diameter If only one tube is used per handhole. If more than one tube is used per handhole then 3 inch tubes are used.

11. The mud drum or mud box is attached by nipples to the bottom of each sinuous header. The mud drum or mud box runs the length of all the sinuous headers to collect sediment and sludge for easier removal. The blowdown line is attached to the bottom of the mud drum or mud box.

12. The steam outlet is on the top of the drum, its position toward the front or rear varies.

13. Sinuous headers are used to allow the combustion gasses to pass over more tube surface than if the tubes were in parallel rows, increasing efficiency. The headers are strong enough not to need stays, unlike box headers.

14. The sinuous header, although perpendicular to the drum, is angled where the tubes connect to the header at 90 degrees. This allows the tubes to be rolled squarely with the header while still having an upward angle from the rear header to the front header. The tubes are angled to allow a better water circulation.

15. The bottom row of tubes is usually made thicker to resist flyash erosion.

16. If the headers are built of cast iron the ASME Code limits their operation to 160 psi. If headers are made of malleable iron then they are limited to 350 psi. If the headers are made of forged steel, then they can be operated up to 1200 psi.

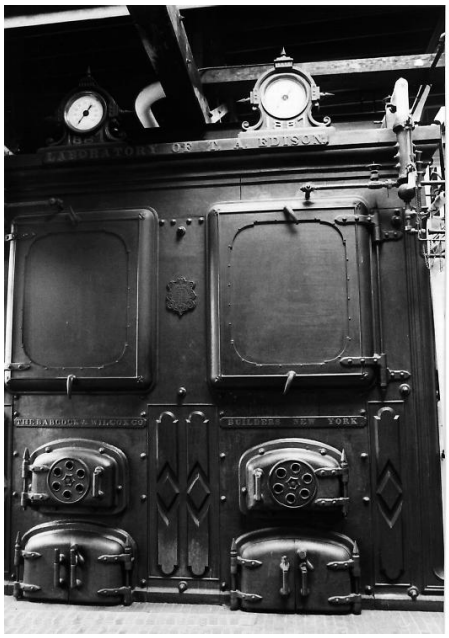
17. The sinuous headers are attached to the boiler by rolled tubes that are attached to a throat sheet or forged cross box at one end of the drum and the top of the sinuous header at the other. The throat sheet is attached to the drum by rivets in the older boilers or by welding in the newer boilers.

18. Drum sizes range from 18 to 72 inches in diameter, with 30 to 38 inches being typical. Drum lengths range from 17 to 22 ft.

19. From the floor to 1/2 the drum, brickwork surrounds the boiler. Large steel doors in the front of the boiler allow access to the sinuous headers.

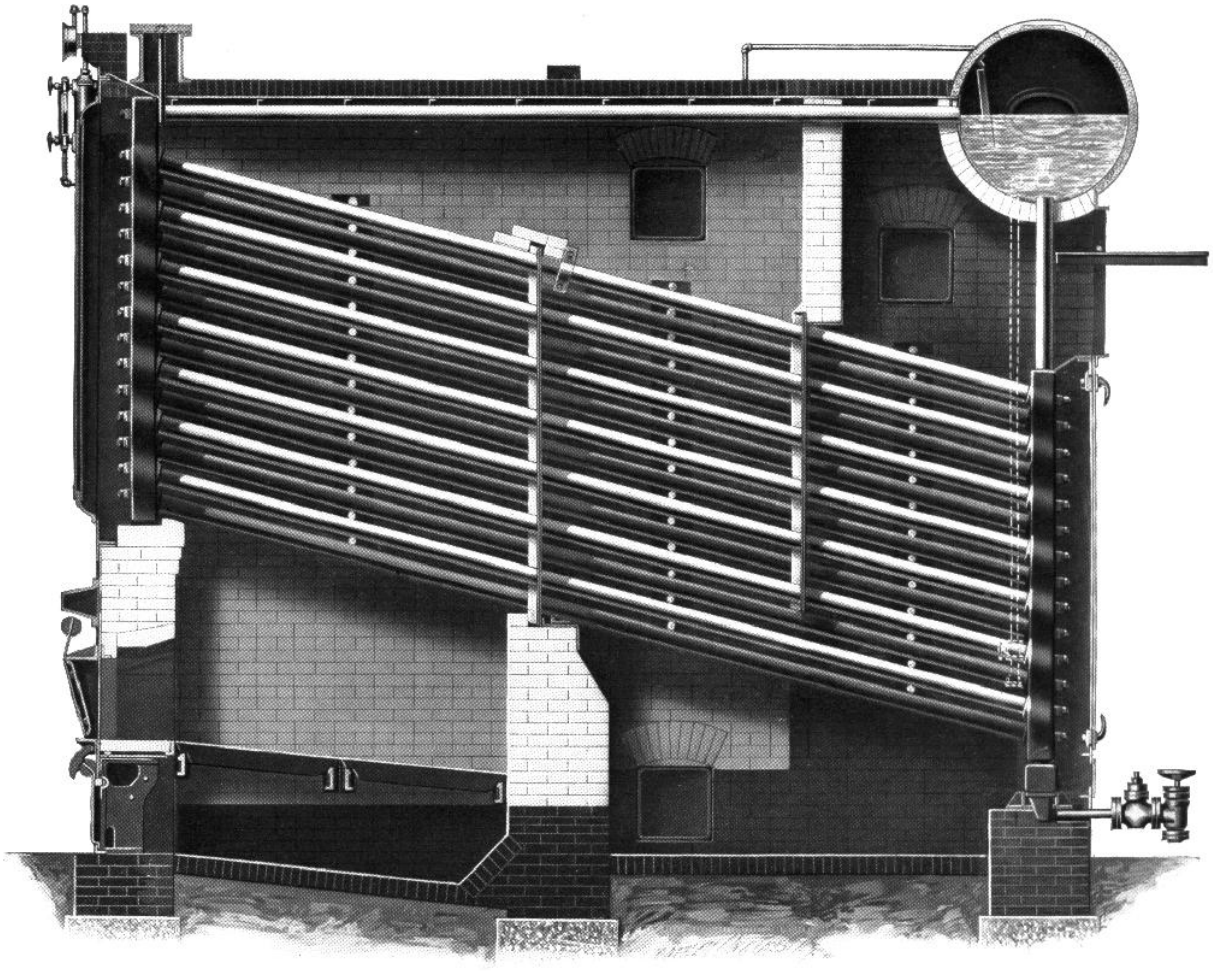
20. The space between the sinuous headers is packed with asbestos

21. Whenever more sinuous headers are required than can fit on the throat sheet, multiple drums are used.



Front of B&W Boiler, Edison Illuminating Co.

BABCOCK AND WILCOX CROSS DRUM BOILER



The Cross Drum boiler is similar to the longitudinal drum in many of its details. The main difference is that the drum is set at 90 degrees to the tubes. The advantage of the cross drum is that the tubes from the top of the sinuous header to the drum can be rolled directly into the drum without using the throat sheet which is a source of weakness. Also the sinuous headers can be tilted so that they are at 90 degrees to the tubes without resorting to a more complex header style. The entire tube bank is inclined from 15 to 22 degrees from horizontal.

Important points to remember about the B & W Cross Drum boiler are:

1. The top row of tubes travel from the front sinuous headers into the drum around the normal water level. A steel plate is mounted inside the drum and extends the length of the drum from the top of the drum to slightly below the water's surface. This prevents the steam from carrying moisture from the top row of tubes over into the steam outlet.

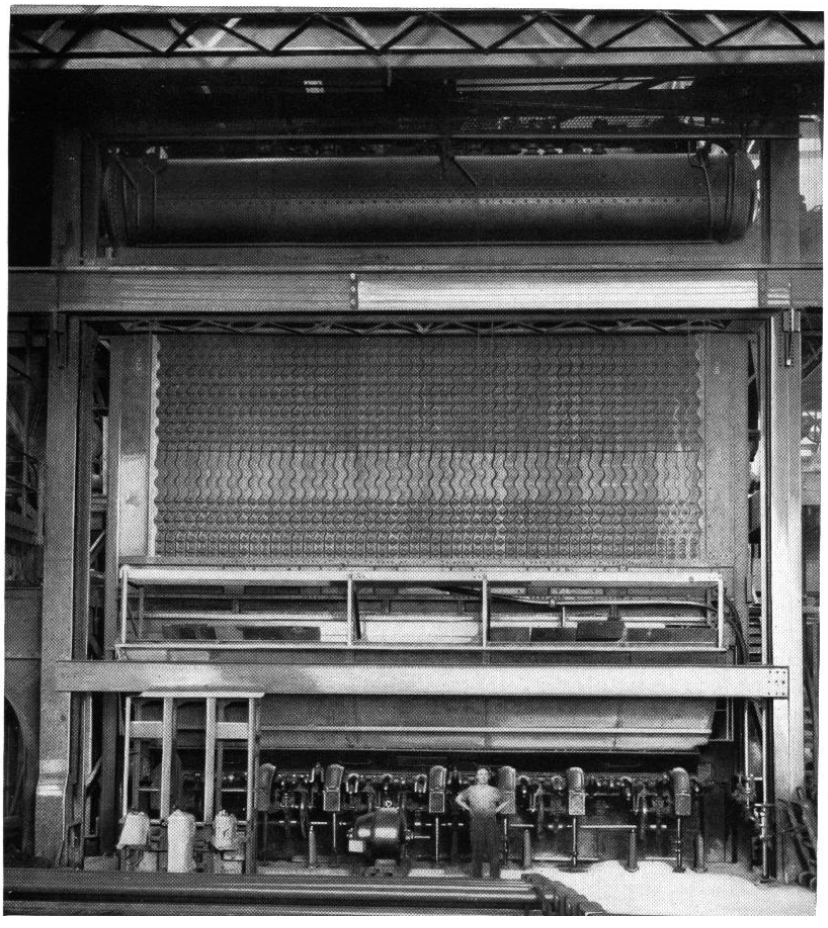
2. The gas passage is similar to the longitudinal drum boiler with the exception that the last gas pass is around the drum.

3. Since the drum is in the rear of the boiler as you are facing the firing doors, the water and steam lines for the water column must be extended from the drum to the front of the boiler.

4. It is easier to construct a wide furnace for a cross drum boiler than for a longitudinal drum boiler. In a cross drum boiler you simply order a longer drum that extends the width of the furnace. In a longitudinal drum boiler you have to add more drums to get the necessary width, which creates more expense. The extra longitudinal drums have the advantage of allowing a higher overload to be carried without priming due to the greater steam disengaging surface provided by the extra drums.

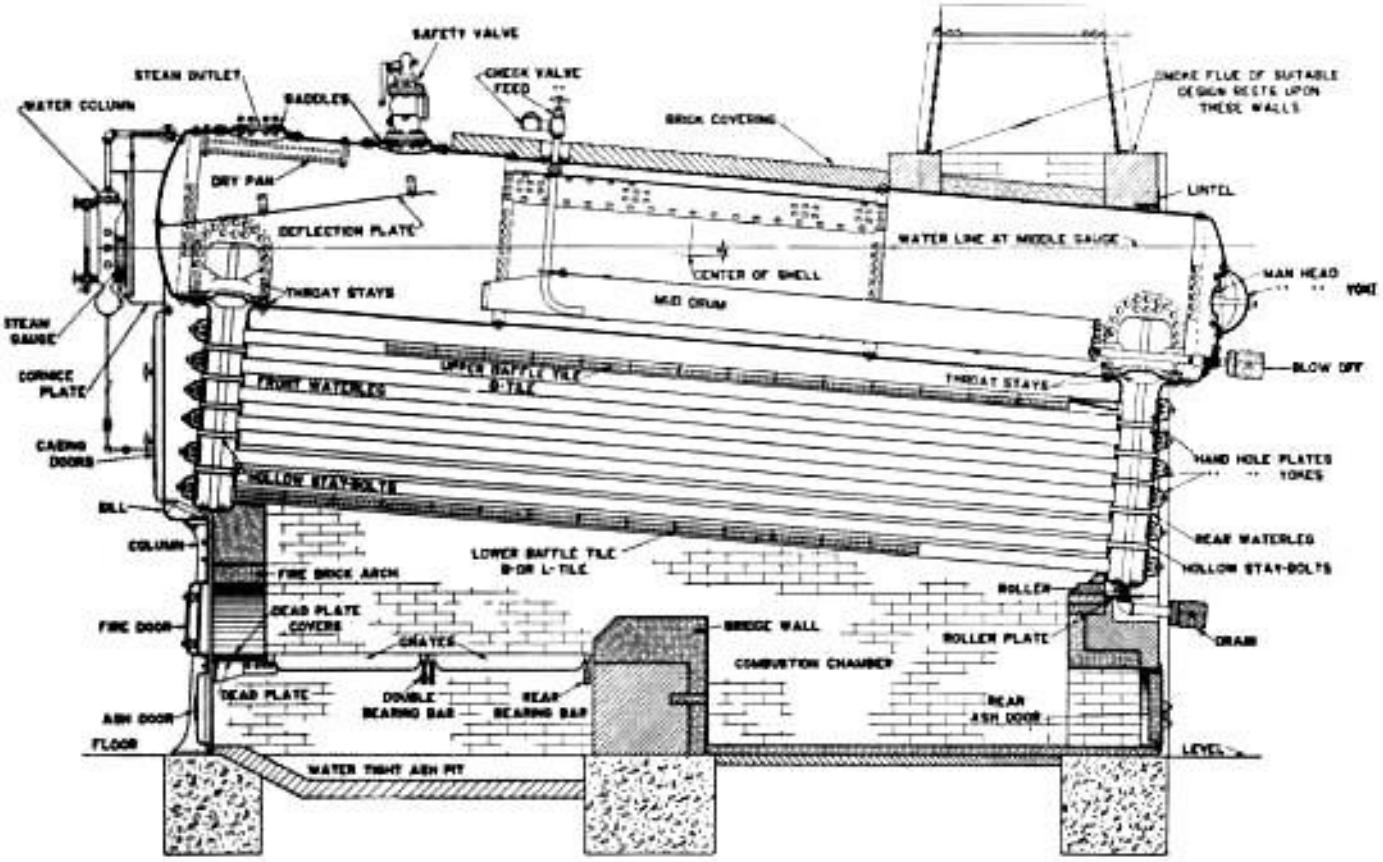
5. The cross drum boiler has a framework of steel I-beams built around it. The drum sits on crosspieces at either end of the drum. The front headers are supported by slingbolts or U bolts attached to the upper I beam.

6. Neither the B & W cross drum nor the longitudinal drum boiler use staybolts in any portion of the boiler. This is an inherent strength of the Babcock and Wilcox design.



Note the size of the Operator compared to the boiler

HEINE BOILER



Longitudinal Section of Heine Standard Boiler.

The Heine Boiler was designed and built by Colonel E.D. Meier in St. Louis in 1882. While the Heine looks similar to the B&W Longitudinal Boiler, there are several differences.

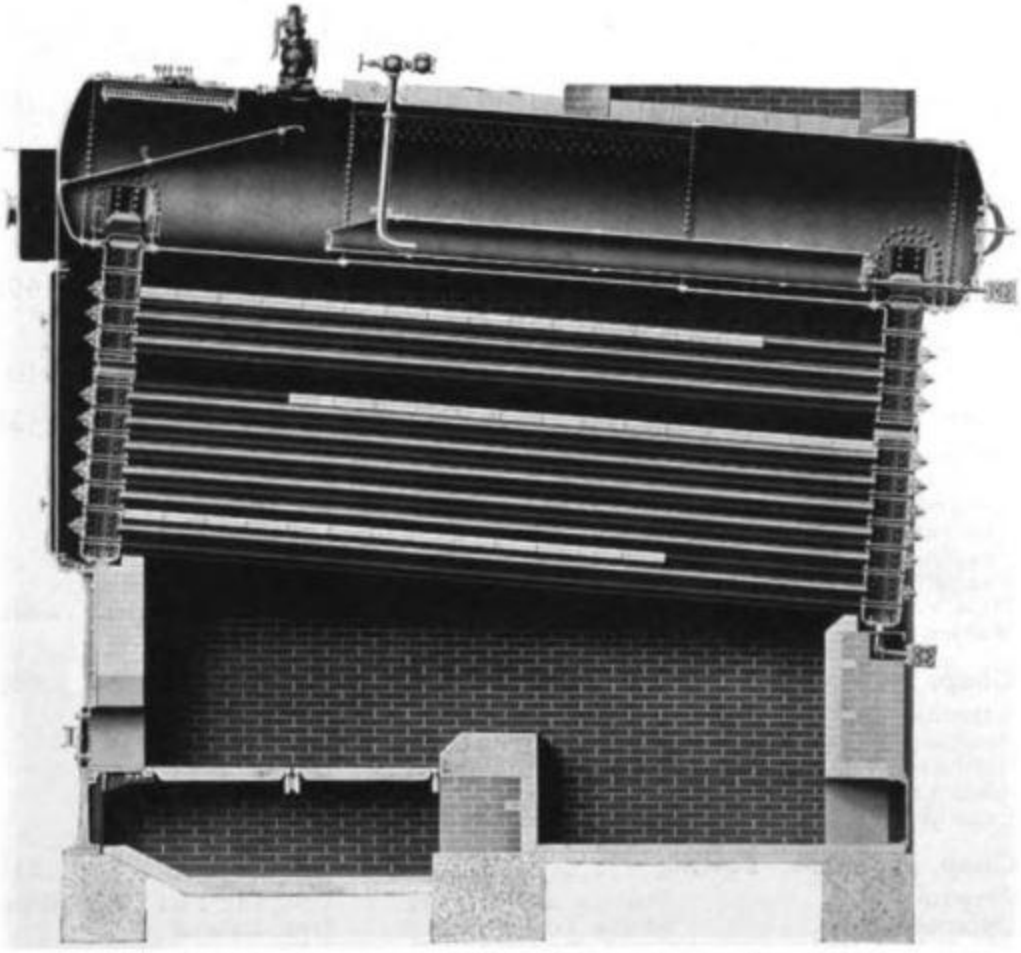
Important points to remember about the Heine boiler are:

1. The fusible plug is located in the front course of the drum, not less than 6 inches above the bottom of the drum, and projecting through the sheet not less than one inch.

2. The water circulation is up through the tubes to the front header, across the drum and then down the back header.

3. Theoretically, water circulation will be more positive in the Heine than the B & W at high ratings because the water box can supply water to all the tubes simultaneously while the B & W supplies water to tubes in a sinuous header through one nipple. In actual practice this is not a problem.

4. The baffles on the Heine are parallel with the tubes while the baffles on the B&W are more perpendicular to the combustion gas flow. The parallel baffles force the gas to travel a longer path before leaving the stack and thereby absorb more heat from the combustion gasses.



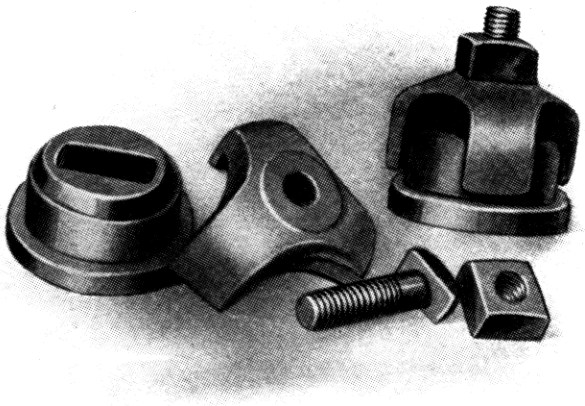
Heine Standard Two Pass Boiler with Setting for Hand Firing.

5. The Heine boiler sits on brickwork and is free to expand upwards.

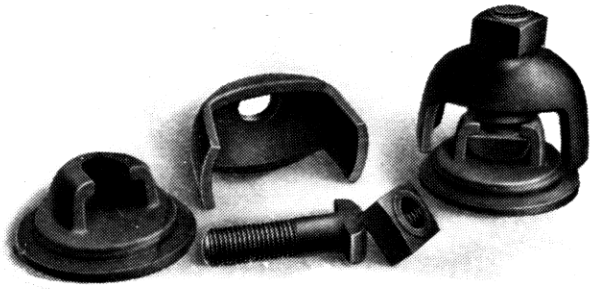
6. The feed line for the Heine enters the top of the boiler and extends downward until near the bottom of the steam and water drum where it turns 90 degrees and the feedwater enters the mud pan. Uniquely, the Heine has the mud drum or mud pan inside the main drum. The claimed advantage is that the incoming feedwater will precipitate out the sludge in the mud pan before it enters the water circulation in the boiler. The Heine will have one blowoff connection from the mud pan and another from the bottom of the back header.

7. In order for the Heine to have an upward angle on the tubes, the entire boiler must be tilted. This means the water level is lower in the front than the rear. The advantage is dryer steam will reach the boiler outlet at the front. The disadvantage is under the same operating conditions, the Heine will overheat quicker for a particular drop in water level than the B&W. The first place to overheat in case of low water will be the steam drum toward the front of the boiler.

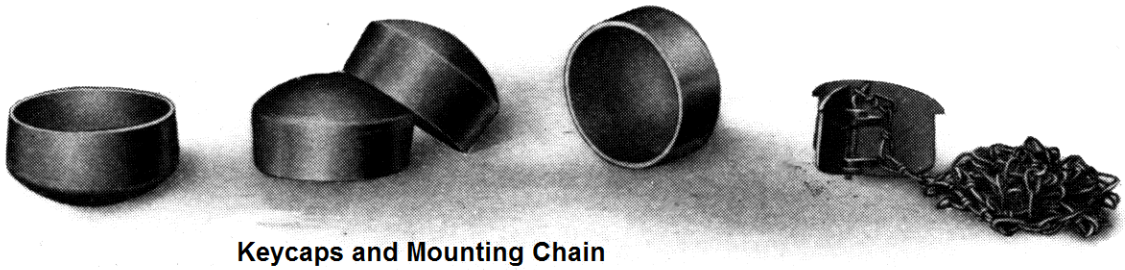
8. The water column is attached at the steam end to the front of the steam drum toward the top. The bottom end of the water column is attached to the front box header, about 8 inches up from the bottom of the box header.



Handhole Plates

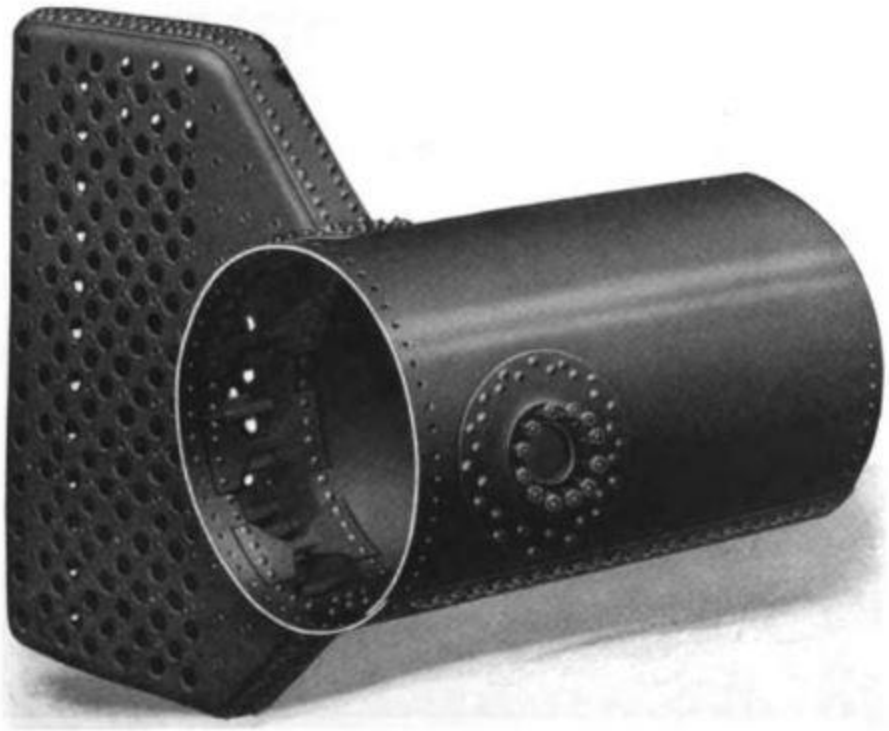


Forged Handhole Plates



Keycaps and Mounting Chain

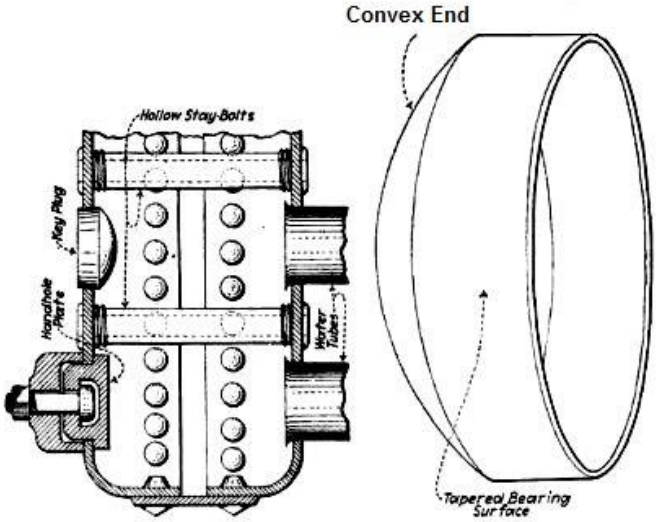
9. While the B&W uses handhole plates to allow access to the tubes for cleaning and replacement, The Heine uses a combination of handhole plates and "key caps". Key caps are hollow cones of steel with the large end of the cone made of solid steel. They were placed in the box header with the large end of the cone toward the water. This allows the boiler pressure to push the cone tighter in the hole. An expander that grips the key cap is inserted in the cone with a chain attached to tighten the key cap. A large brass, wooden or leather mallet is used to drive the key cap out for inspection after draining. The handholes allow old key caps to be removed and new ones inserted. A Manhole is located in the rear of the steam drum.



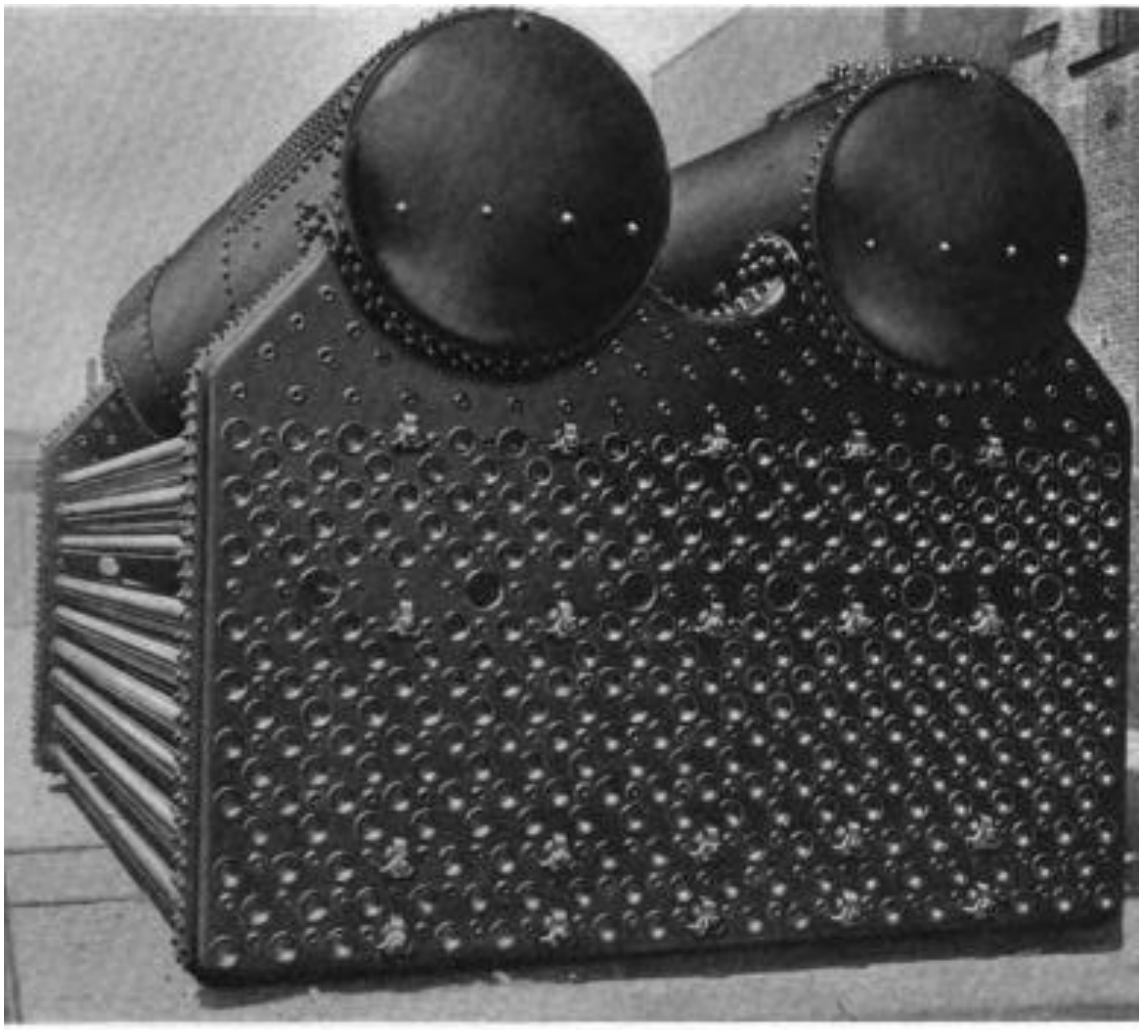
Section of Drum and Waterleg of Heine Standard Boiler.
Note the Large Throat Area.

10. The B&W Boilers use sinuous headers while the Heine Boiler uses the box header. The box header consists of two large plates of steel, the outside edges of which are turned in to form a mating surface for a strap of steel connected by a single riveted lap joint on each side that connects the inner and outer steel plates.

Hollow staybolts



11. Because of the large area of flat steel plates that would bulge under pressure, hollow staybolts are use to hold the plates together. The bolts are made hollow to warn of a crack in the bolt. The steam that would blow through the hollow core should a staybolt fail. Sootblowers can be used through these hollow staybolts to clean the soot from the tubes.



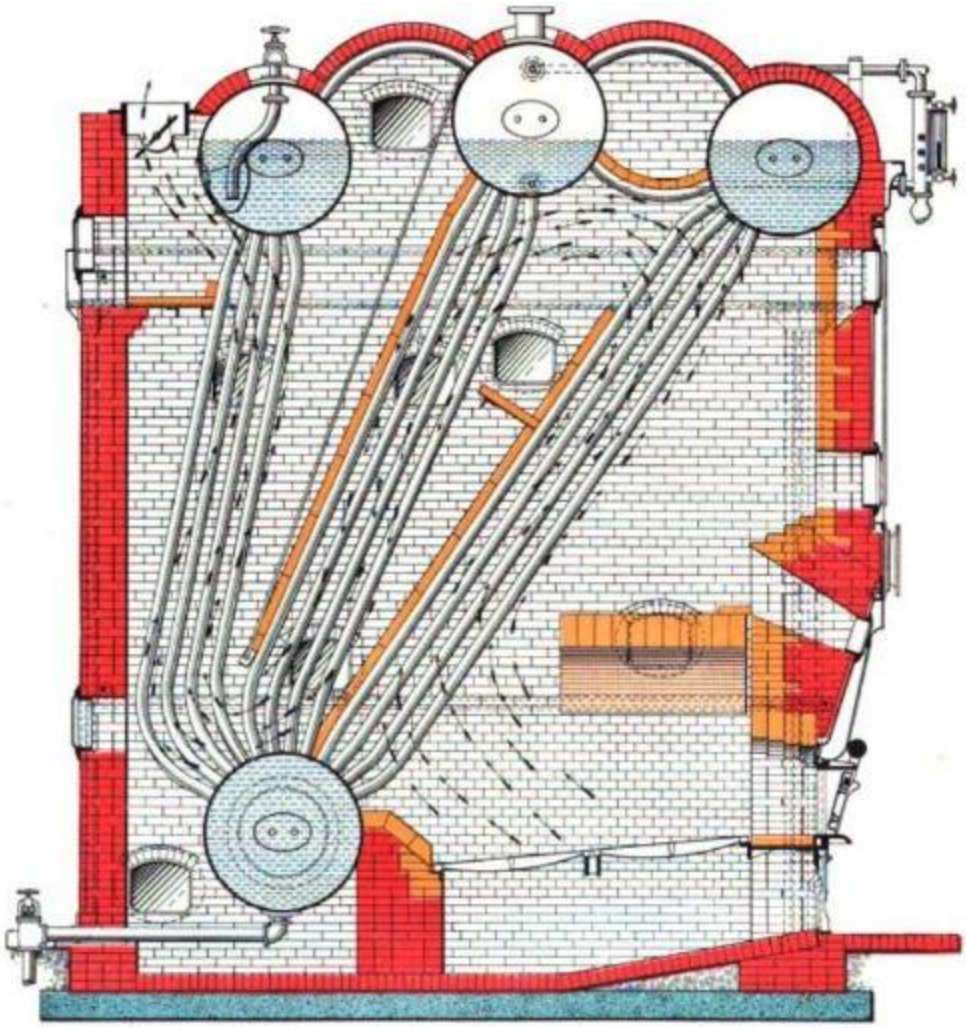
Heine Standard Double Drum Boiler with Key Handhole Caps.

12. The Heine boiler is built so that the drum is parallel to the ground when set on a flat surface. This allows the box header to be attached to the throat sheet perpendicular to the drum. This also allows the tubes to be at 90 degrees with the box header so that the tubes can be rolled tightly. The end result is that the Heine is not as complex to construct as the B&W Boiler. The B&W boiler drum would be at a 15 to 22 degree angle when set on a level surface.

13. Both the B&W and the Heine are three gas pass boilers. Heine claims that the parallel or longitudinal baffles are more efficient while B&W claims that their perpendicular baffles are. The parallel baffles are easier and less expensive to install and maintain than the perpendicular baffles of the B&W.

14. Tubes in the Heine are 3 1/2 inches in diameter.

STANDARD STIRLING BOILER

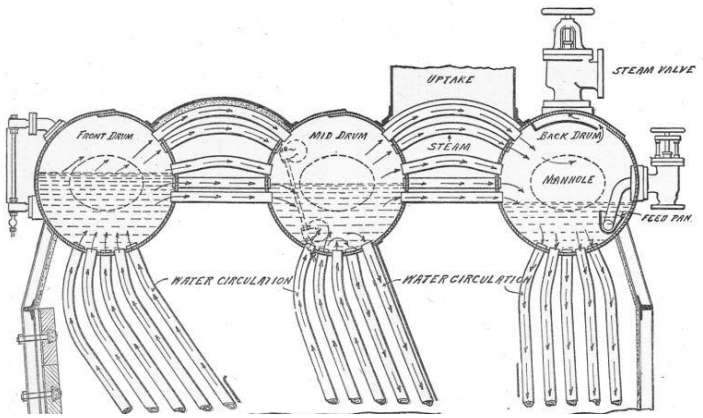


The Standard Stirling Boiler was patented in 1888 by Alan Stirling and was one of the most successful boiler designs. Its use of multiple drums and curved tubes led to the development of the modern utility boiler designs being used today. The Standard Stirling consists of three steam and water drums connected to one mud drum. The front and middle drums are connected by both water and steam circulating tubes. The water circulating tubes help equalize the water level in the drums while the steam circulators provide a path for the steam to travel to the rear drum where the steam outlet is located. The middle and rear drums are connected only by a set of steam circulating tubes. The three upper drums give a large area for the steam to leave the surface of the water. This means that the boiler can be fired heavily without causing priming or carryover into the steam line. This boiler is usually between two and three stories high. The curved tubes allow the tubes to be rolled perpendicular to the drum while spaces between the tubes allow the tubes to be replaced.

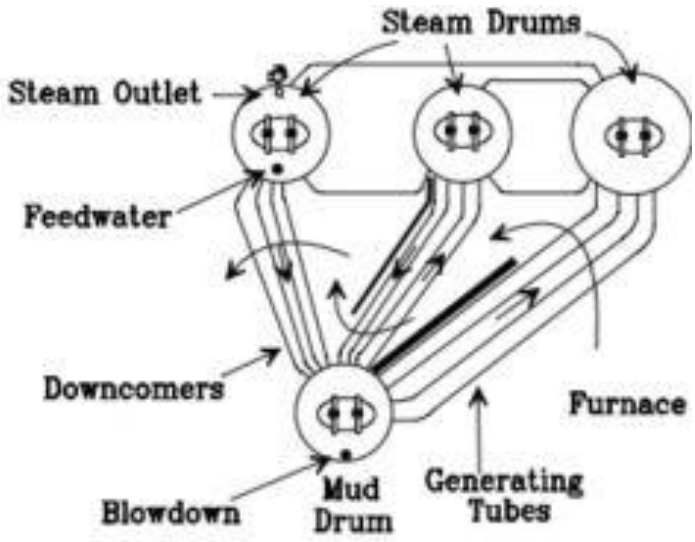
Important points to remember about the Standard Stirling boiler are:

1. If the boiler has no superheater, the fusible plug is located 4" up from the bottom of the middle drum toward the front of the boiler, and projecting through the sheet not less than one inch. If the boiler does have a superheater the fusible plug is located 4 inches up from the bottom of the front drum, and projecting through the sheet not less than one inch.

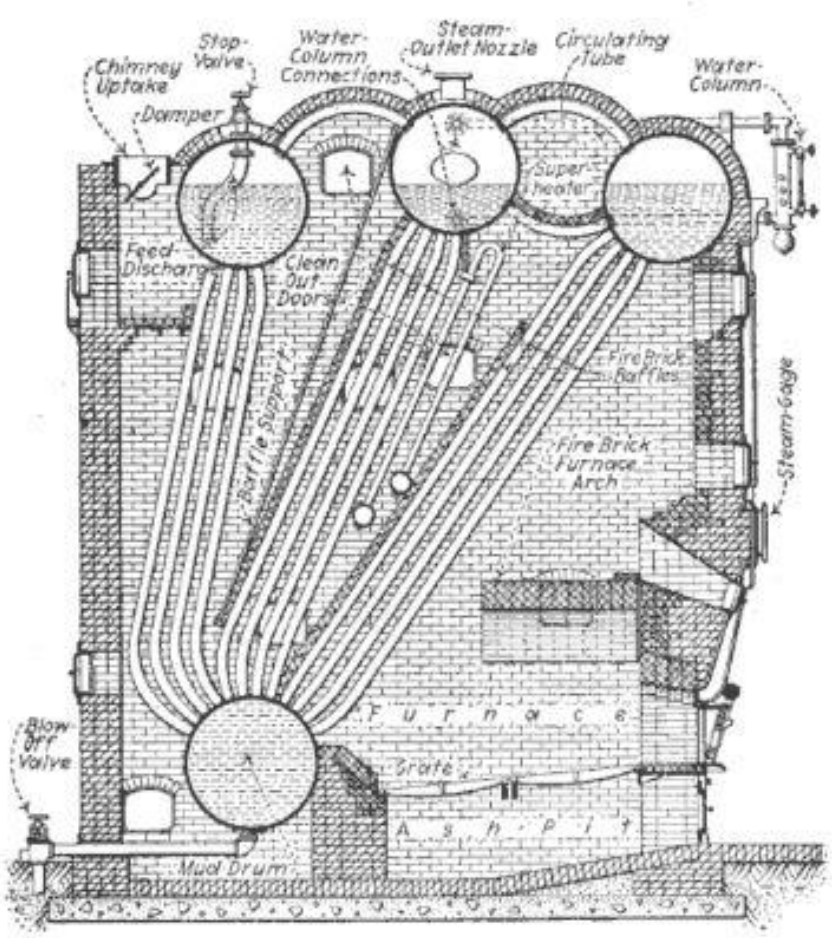
Front of the Boiler



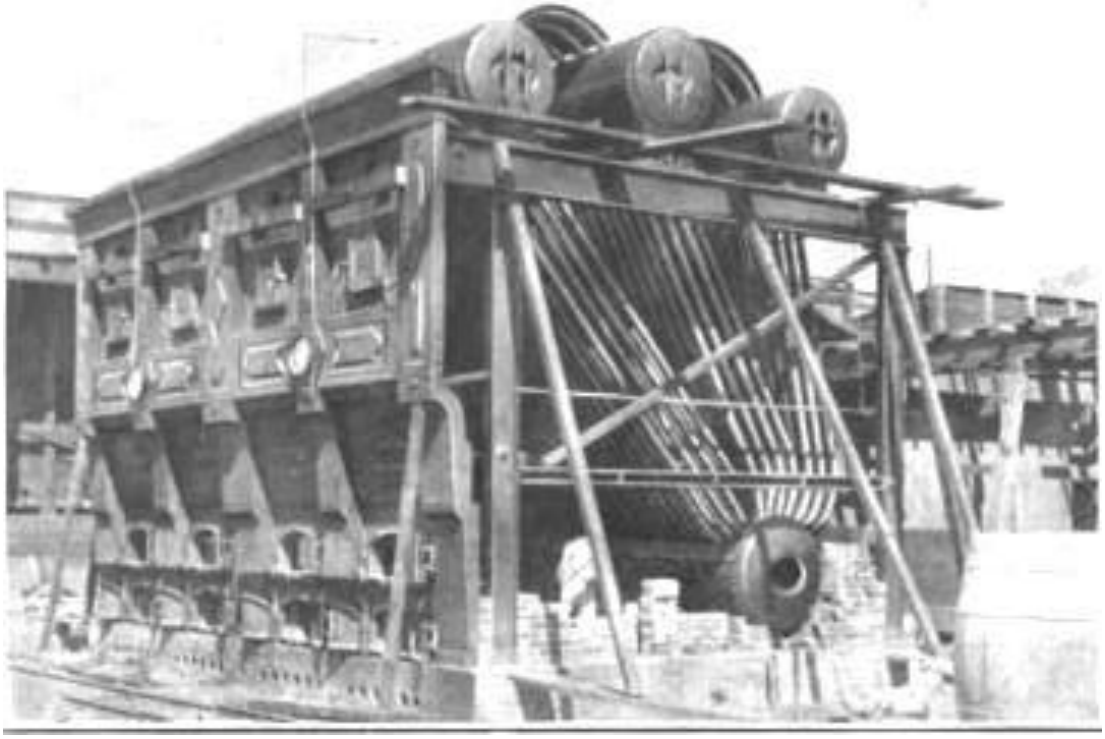
2. The feedwater enters the rear drum and discharges into a trough that runs 2/3 the length of the drum. From the rear drum the water travels down into the mud drum. From the mud drum the water travels up into the front steam and water drum. From there the water travels through the water circulating tubes that connect the front and middle drums into the middle drum. From the middle drum the water travels down the middle row of tubes to the mud drum and then up in a circular path back into the front drum.



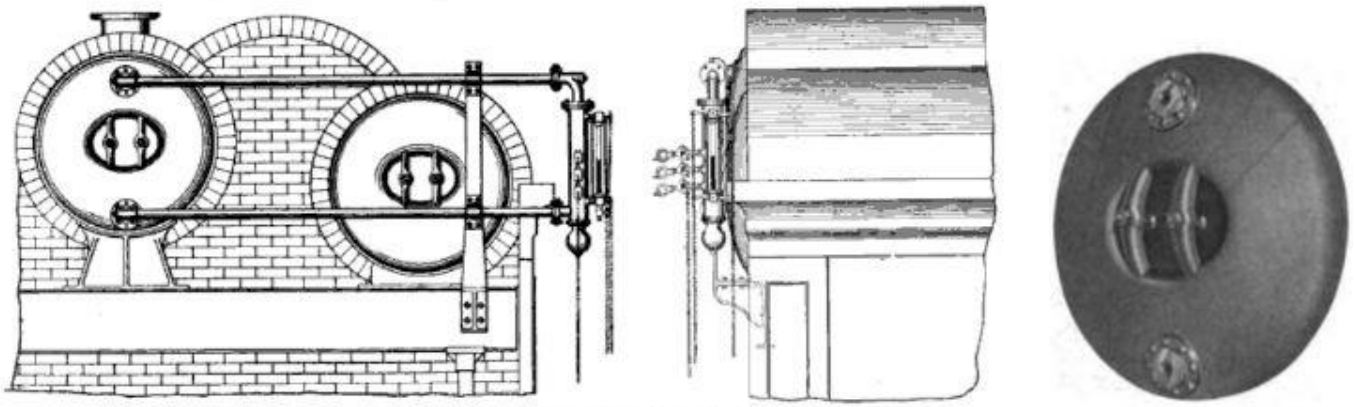
3. This is a three gas boiler. The combustion gasses pass over the bridge wall and upward along the first baffle. The first pass has the radiant heat of the fire on the front row of tubes as well as the convection heat. The gasses then go down between the first and second baffle, heating the middle tubes. The gasses reverse flow again at the mud drum and pass upward over the back row of tubes and out the breeching to the chimney.



Drainable Superheater between 1st and 2nd Pass



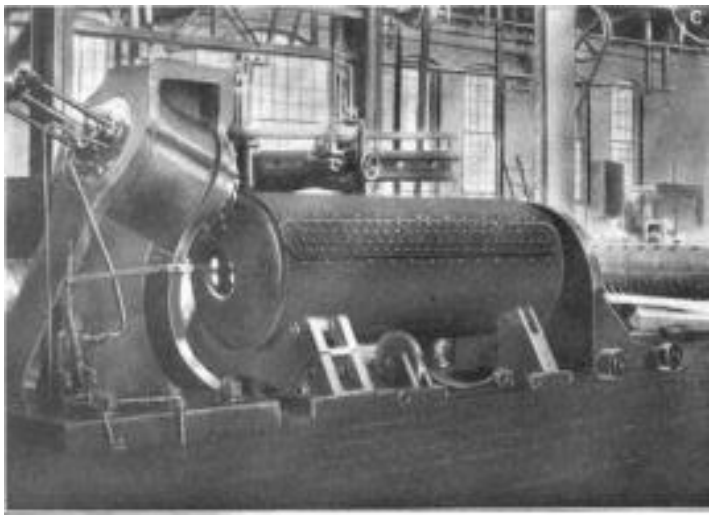
4. The boiler is supported by having the steam and water drums hung by saddles attached to a surrounding "I" beam structure. The tubes and the mud drum hang from the steam and water drums, the mud drum being held by the tubes. The expansion of the boiler is downward and to the rear. Asbestos packing around the bridge wall prevents the combustion gasses from leaking past the mud drum.



WATER COLUMN AND CONNECTIONS, WITH QUICK-CLOSING GAUGE GLASS FITTINGS

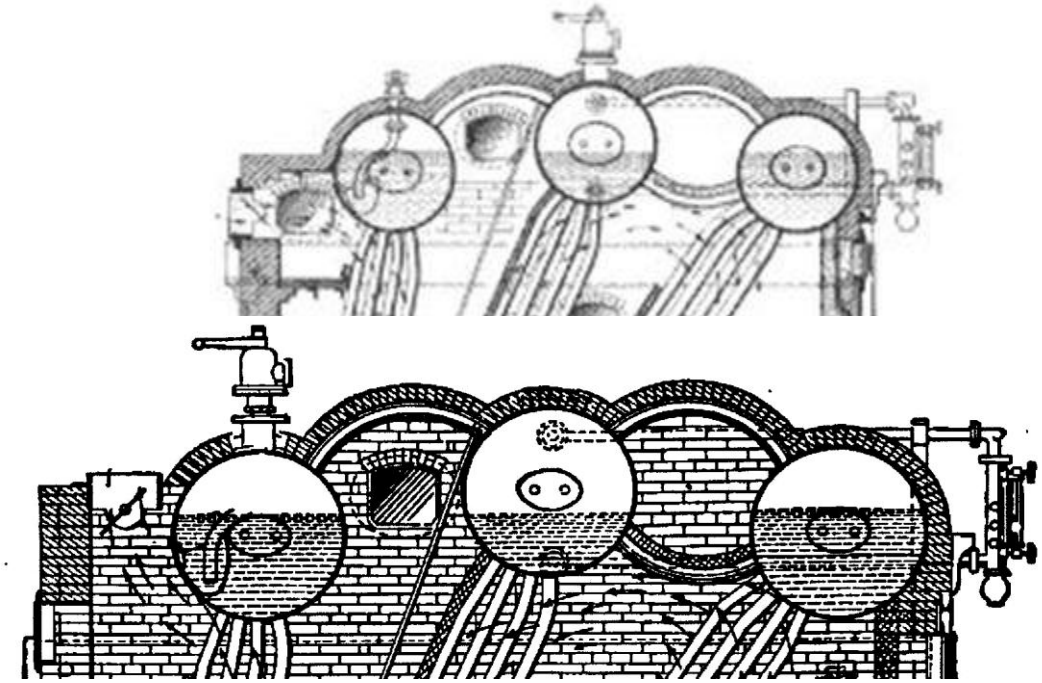
5. The water column is connected to the middle drum because it has the most stable water level. The piping from the middle drum extends to the front of the boiler and connects to the water column.

6. Manholes are provided in one end of each drum. Some boilers may have manholes in both ends of each drum. The boiler steel is thicker at the ends of the drums than the middle to strengthen the area around the manhole openings.



8. The mud drum is the shortest in length but is the largest in diameter so sufficient room is provided to roll tubes from the steam and water drums. It is usually 4 to 10 inches larger in diameter than the steam drums.

9. The first place to overheat in the event of low water would be the bottom of the steam drum in the front of the boiler over the furnace.



9. The safety valves are normally located on the rear drum. Earlier models were on the middle drum.

10. The steam discharge nozzle can either be on the middle drum (earlier types) or on the rear drum (later types).

11. There are usually two bottom blowdown lines on the mud drum, one at either end.

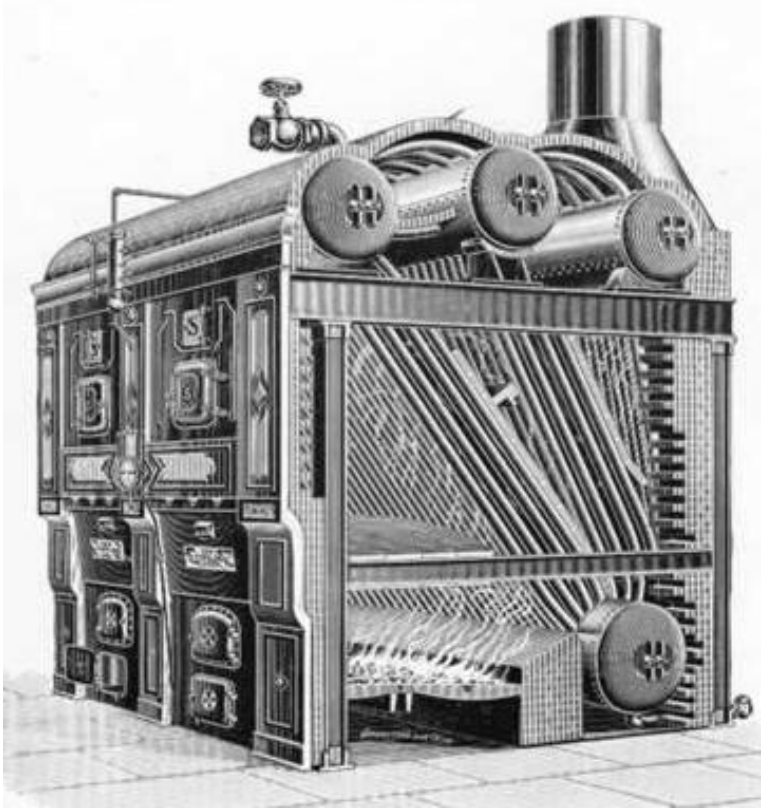
12. The continuous blowdown is on the middle drum just under the surface of the normal water level.

13. The tubes are curved to meet the holes in the drum at a 90 degree angle for rolling.

Baffles help prevent priming and Carryover

14. All the tubes in this boiler are flared. All the tubes in the very top row of the mud drum should be beaded and every tube in the very bottom row of the steam and water row should be beaded to allow air to escape the mud drum upon filling and the water to go into the mud drum upon draining. Sometimes only every other tube is beaded in the top and bottom rows, which have the same effect with less labor costs. Tubes in all water tube boilers can extend beyond the tube sheet no less than 1/4 inch and no more than 1/2 inch before flaring.

15. Tubes in the Stirling boiler are either 3" or 3 and 1/2" in diameter.



ADVANTAGES OF THE STANDARD STIRLING BOILER

1. It has a large area of heating surface, and can therefore generate many pounds of steam per hour for the amount of space it occupies.

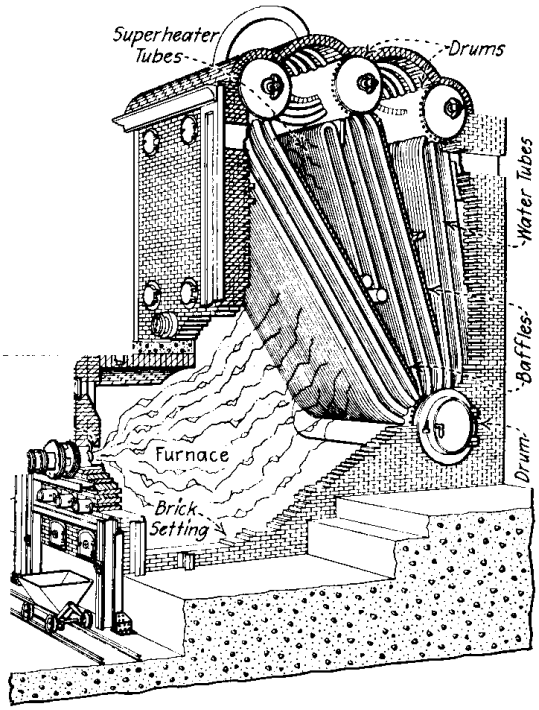
2. It has rapid circulation.

3. The water is spread among many tubes so that explosion hazards are reduced.

4. Pressures can be higher than in fire tube boilers.

5. It takes a small amount of floor space for the amount of steam generated.

6. If you have the proper furnace design, you can successfully burn any fuel in this boiler

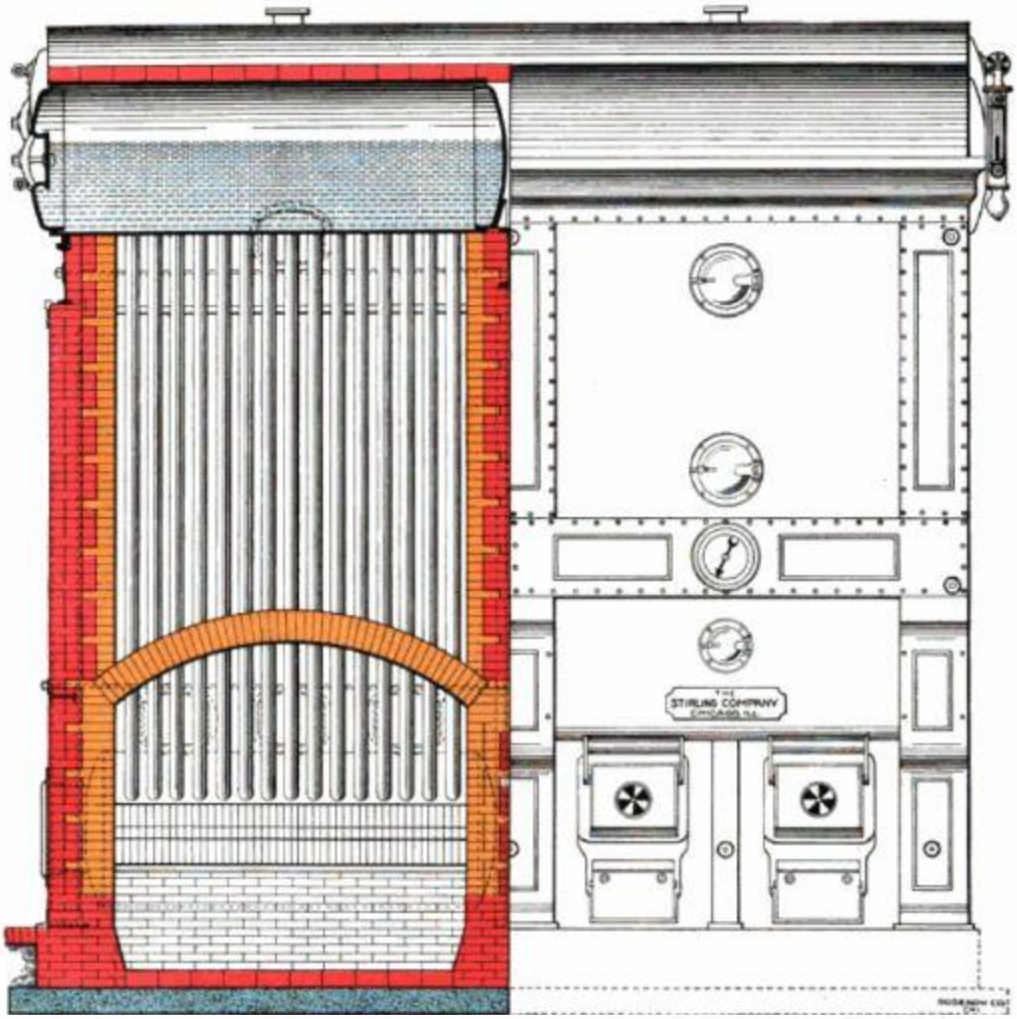


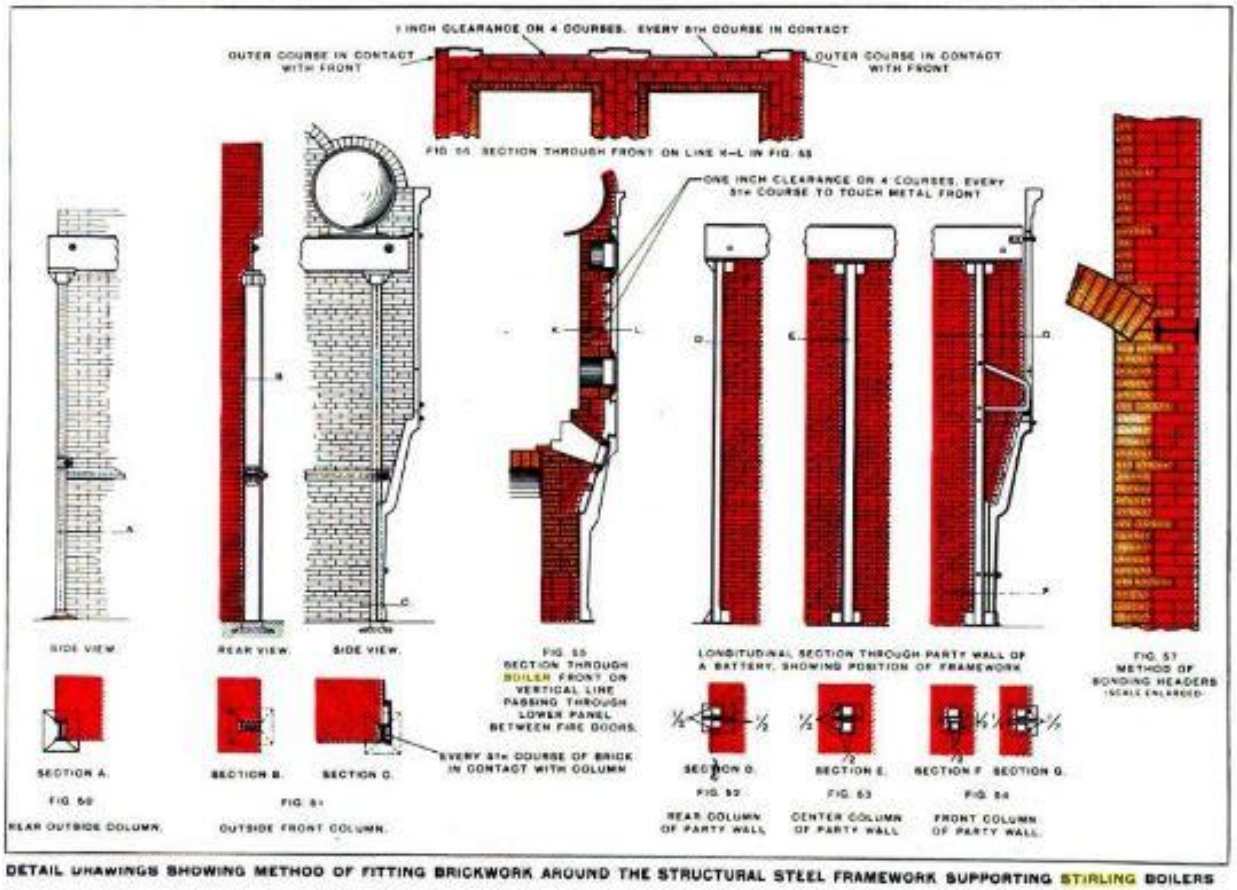
DISADVANTAGES OF THE STANDARD STIRLING BOILER

1. The boiler must be erected on site which means it is more expensive to build.

2. Because of the curved tubes you cannot see down the tubes for scale without special equipment.

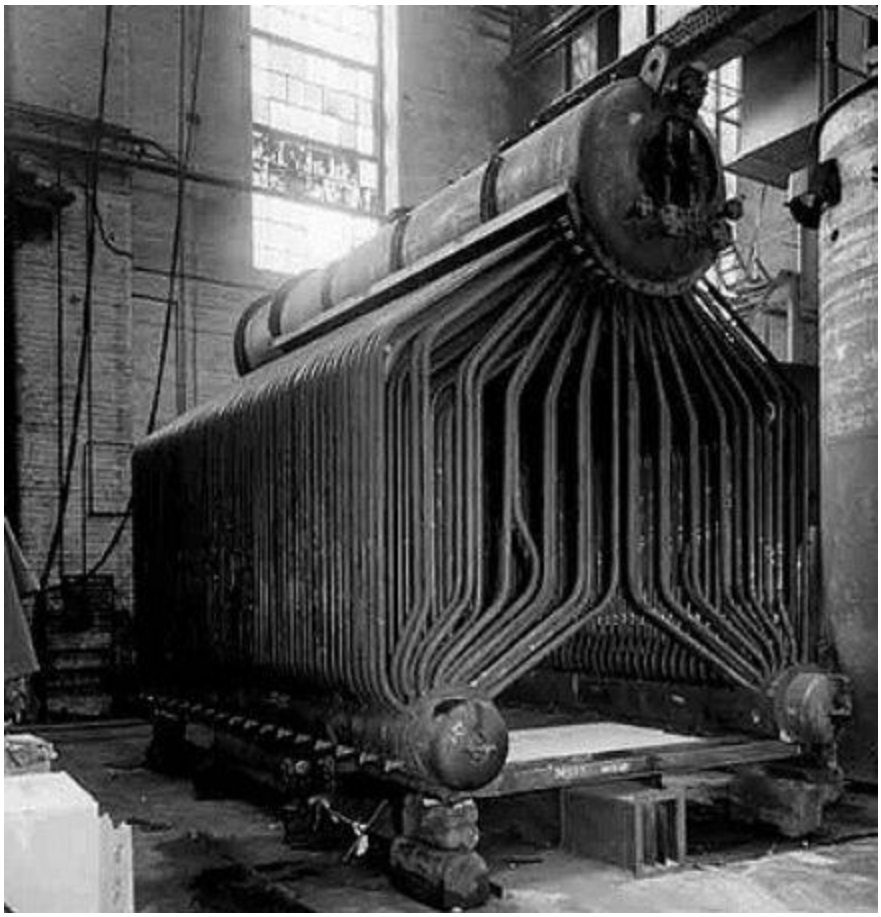
3. The use of curved tubes of different shapes means that many different styles of tubes must be kept on hand in case a replacement is needed. There are tubing companies that keep records of boiler tubes from different boiler manufacturers and can quickly bend a replacement tube to original specifications.



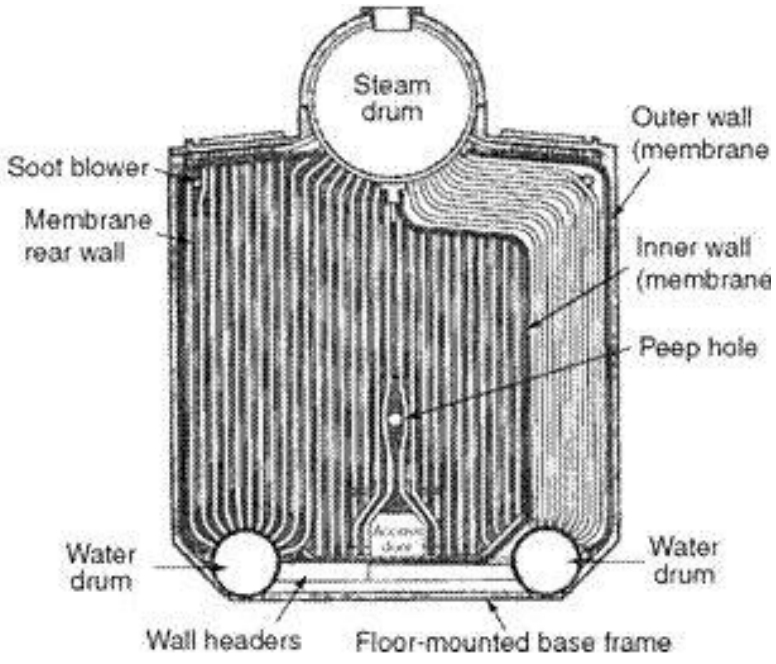

1 INCH CLEARANCE ON 4 COURSES. EVERY 5th COURSE IN CONTACT
OUTER COURSE IN CONTACT WITH FRONT
OUTER COURSE IN CONTACT WITH FRONT
FIG. 54. SECTION THROUGH FRONT ON LINE K–L IN FIG. 55
ONE INCH CLEARANCE ON 4 COURSES. Every 5th COURSE TO TOUCH METAL FRONT
SIDE VIEW.
REAR VIEW.
SIDE VIEW.
FIG. 55
SECTION THROUGH BOILER FRONT ON VERTICAL LINE PASSING THROUGH LOWER PANEL BETWEEN FIRE DOORS.
LONGITUDINAL SECTION THROUGH PARTY WALL OF A BATTERY, SHOWING POSITION OF FRAMEWORK
FIG. 57
METHOD OF BONDING HEADERS
SECTION A.
FIG. 50
REAR OUTSIDE COLUMN.
SECTION B.
SECTION C.
FIG. 51
OUTSIDE FRONT COLUMN.
EVERY 5th COURSE OF BRICK IN CONTACT WITH COLUMN
SECTION D.
FIG. 52
REAR COLUMN OF PARTY WALL
SECTION E.
FIG. 53
CENTER COLUMN OF PARTY WALL
SECTION F
SECTION G.
FIG. 54
FRONT COLUMN OF PARTY WALL.

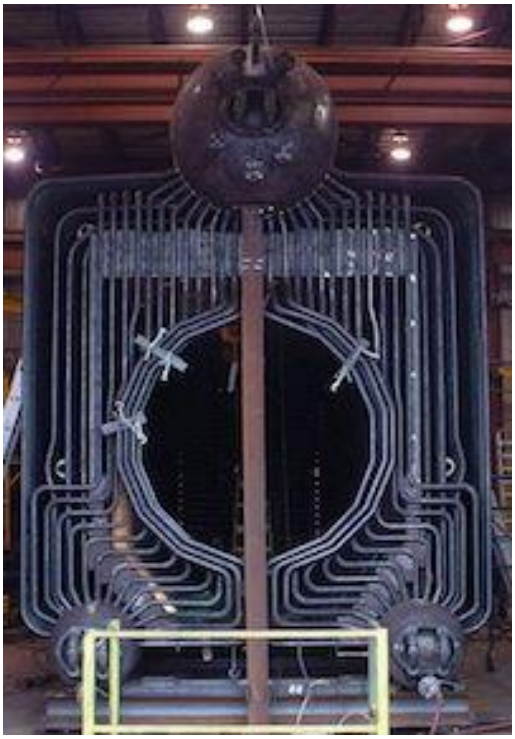
DETAIL DRAWINGS SHOWING METHOD OF FITTING BRICKWORK AROUND THE STRUCTURAL STEEL FRAMEWORK SUPPORTING STIRLING BOILERS

WICKES "A" BOILER



The boiler is called an "A" boiler due to its design of having one steam and water drum at the top with two mud drums at the bottom sides connected by tubes. This design gives a large furnace area for a small height and floor space. This means that the boiler can give good economy whether burning gas or oil and is used often as a dual fuel boiler. This style of boiler has been manufactured by various companies for many years and has given very satisfactory service. Erie City, Nebraska, Union Iron Works, and Indeck have all manufactured A type boilers.





Important things to remember about the Wickes A Boiler are:

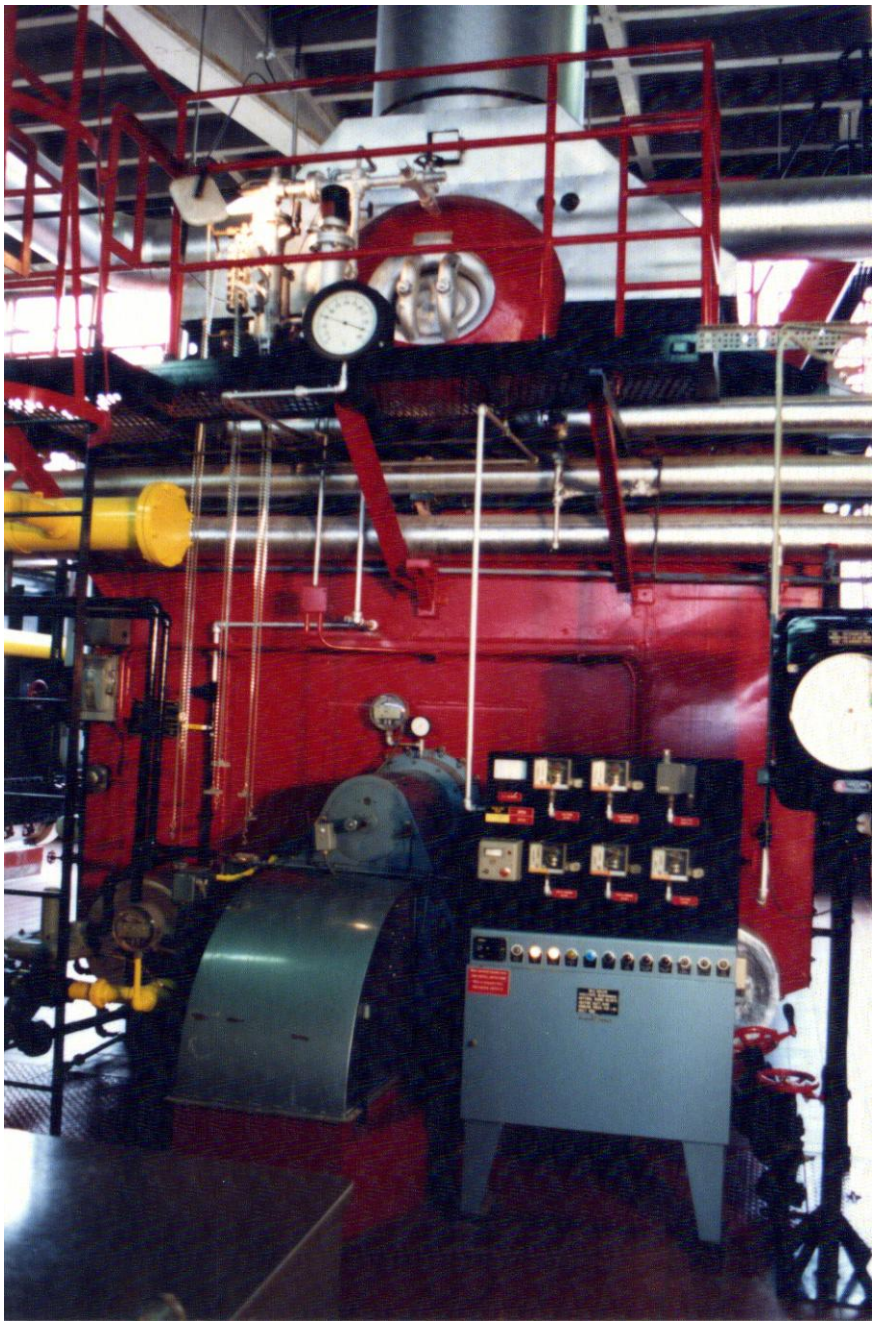
1. If required, the fusible plug will be 6 inches up from the bottom of the steam drum, toward the front of the boiler.

2. The water circulation is up the inside rows of tubes closest to the furnace and down the outside rows of tubes.

3. The tube banks in this boiler are separated by baffles that force the combustion gasses to travel to the rear of the boiler before they reverse and come back toward the front. If one baffle is used, then the boiler is a two gas pass unit and the stack is at the front. If two baffles are used, then the boiler is a three gas pass unit and the stack is at the rear.

4. This boiler is usually mounted on a foundation with the mud drums being off the floor. The fresh air for combustion then travels between the foundation and the floor of the boiler, slightly preheating the air. The entire outside of the boiler is encased in sheet steel to prevent air leakage. Expansion of this boiler is upward.

5. Feedwater enters the top drum of the boiler in the front and travels 2/3 the length of the boiler before discharging.



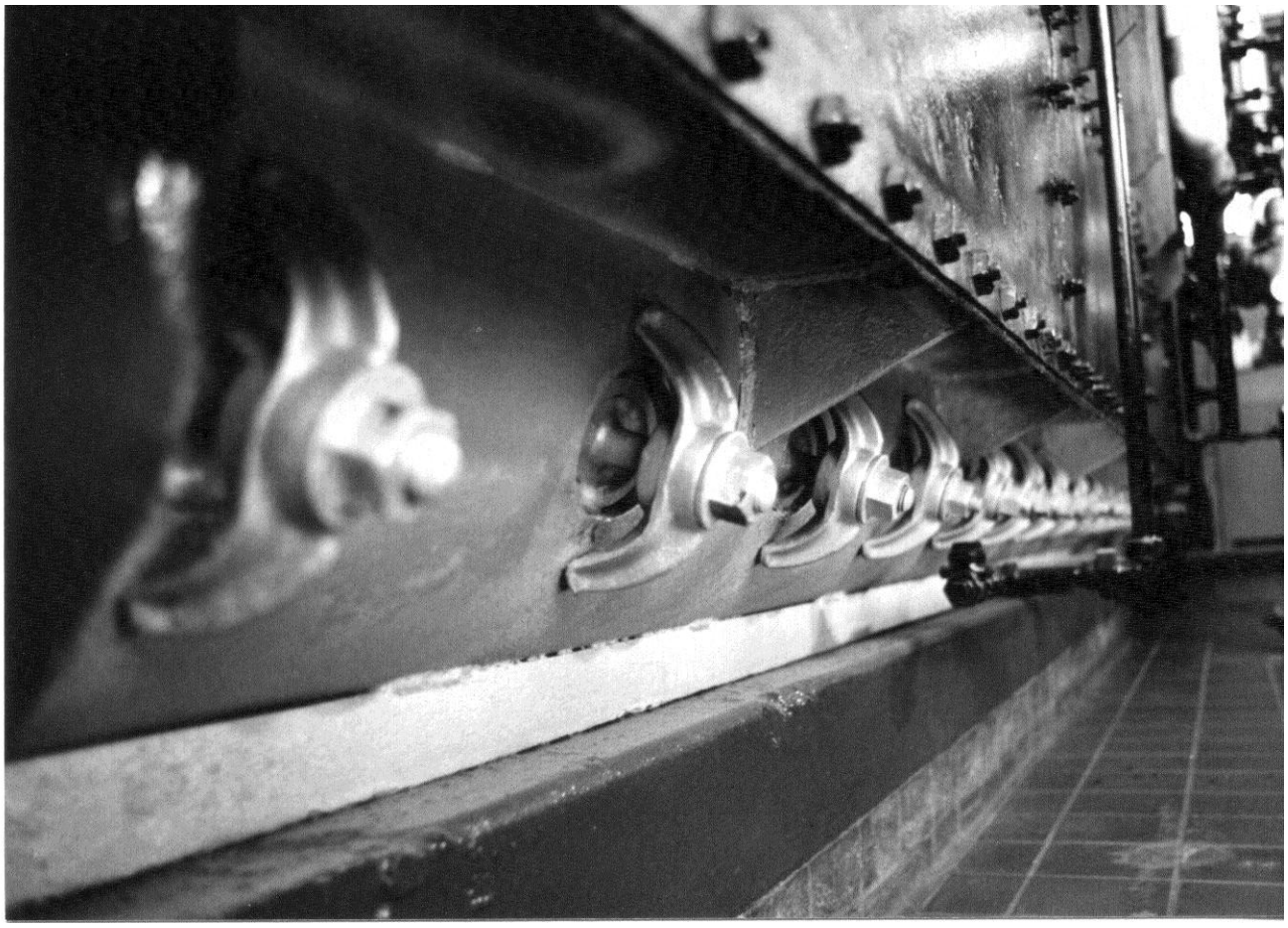
6. The first place to overheat in the event of low water will be the bottom of the steam drum at the front of the boiler.

7. The water column steam connection is attached to the front of the steam drum at the top. The water connection is attached to the front of the steam drum at the bottom.

8. Manholes are in either end or both ends of the top drum.

9. The boiler has a row of tubes coming from each end of the steam and water drum that will act as waterwalls on the front and back wall to generate more steam and help protect the brickwork on the front and back walls from the heat of the fire.

10. The mud drums are usually too small to enter and large hand hole plates are located at both ends of the mud drums. Numerous small handholes are located along the length of each mud drum to access the tubes for cleaning or rolling of replacement tubes. This boiler has a blowdown line from each mud drum.



Bottom Header of Wickes A Boiler showing Forged Steel Handhole Plates, Handhole Yokes and Nuts after cleaning, painting, and installing new Flexatallic gaskets. Some handhole plates sold today have welded studs on the Handhole Plates that can be snapped off if you put too much torque on them. Buy Forged Steel.

Chapter 6 Questions

1. Where is the fusible plug located in the Wickes vertical watertube, the B&W longitudinal and cross drum boiler, Heine, Stirling, and Wickes "A" boiler?
2. Describe the water circulation in the Wickes vertical water tube boiler.
3. How is the Wickes vertical watertube boiler supported?
4. What is the "Dutch Oven"?
5. What are the advantages of the Wickes vertical watertube boiler?
6. Describe the water circulation of the B&W longitudinal drum boiler.
7. What materials are the sinuous headers made from and what is the maximum pressure allowed on each type?
8. How are tubes cleaned in the B&W longitudinal boiler?
9. How are the sinuous headers attached to the drum?
10. Which can handle overloads better, the B&W cross drum or a multiple drum B&W longitudinal drum boiler?
11. How is the box header constructed on the Heine?
12. What are two purposes for hollow stay bolts?
13. Which is easier to construct, the Heine or the B & W?
14. Which boiler has "key caps" the Heine or the B & W?
15. Why do they call the Stirling the forerunner of modern boilers?
16. Where is the safety valve on the Stirling?
17. Where is the feedwater inlet on the Stirling?
18. Where is the water column connected on the Stirling?
19. Where is the steam outlet on the Stirling?
20. Why are some tubes beaded in the Stirling boiler?
21. What is the advantage of the Wickes A design?
22. How can you tell if the Wickes A is a two pass or a three pass boiler?
23. Explain the water circulation in the Wickes A boiler.

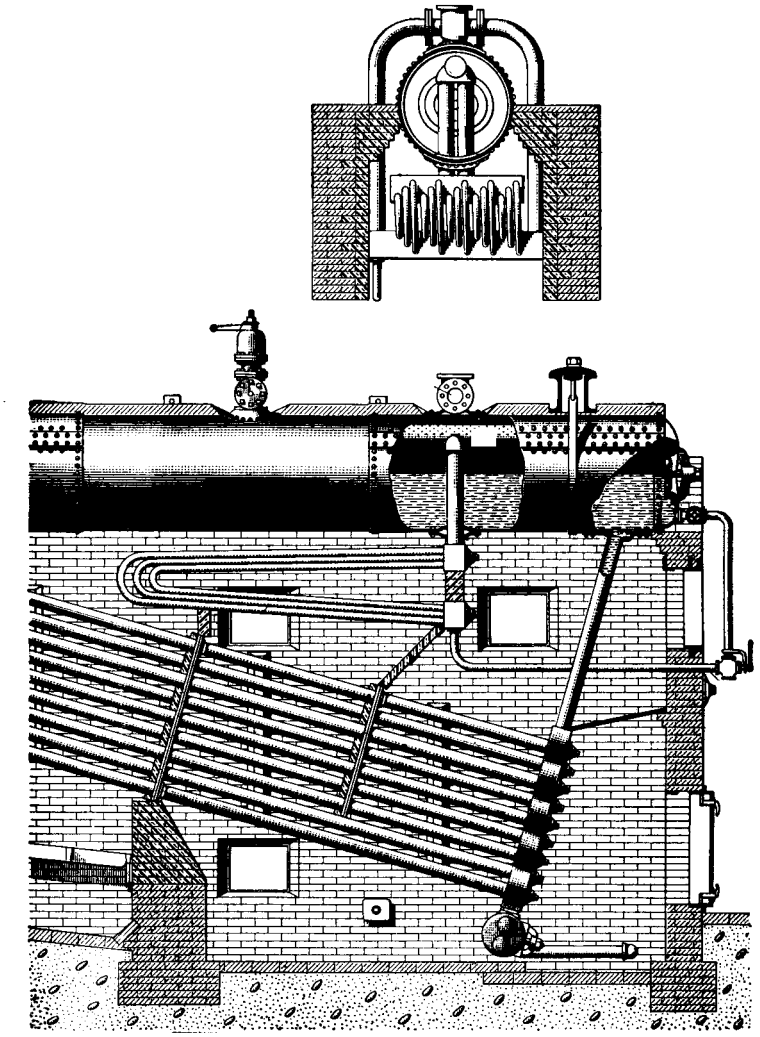
Chapter 7

SUPERHEATERS, ECONOMIZERS, and AIR PREHEATERS

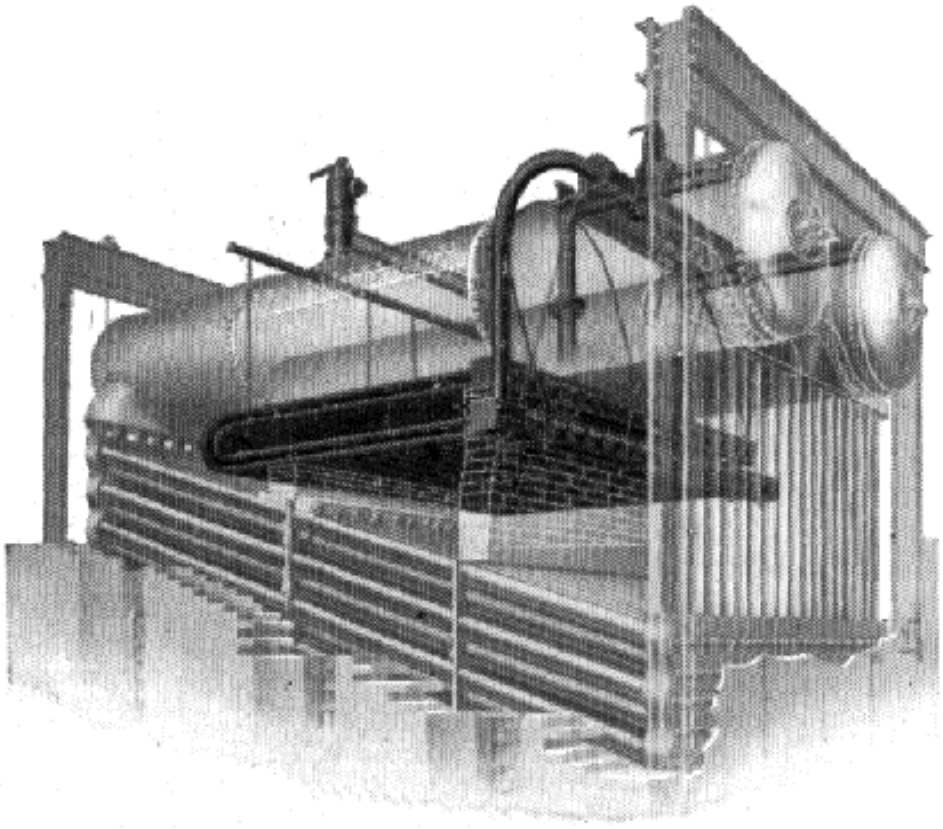
SUPERHEATERS

As discussed in our first chapter, superheaters are used to bring steam to a higher temperature than normal boiler designs can provide. Steam has to be taken away from the surface of the water before it can be superheated.

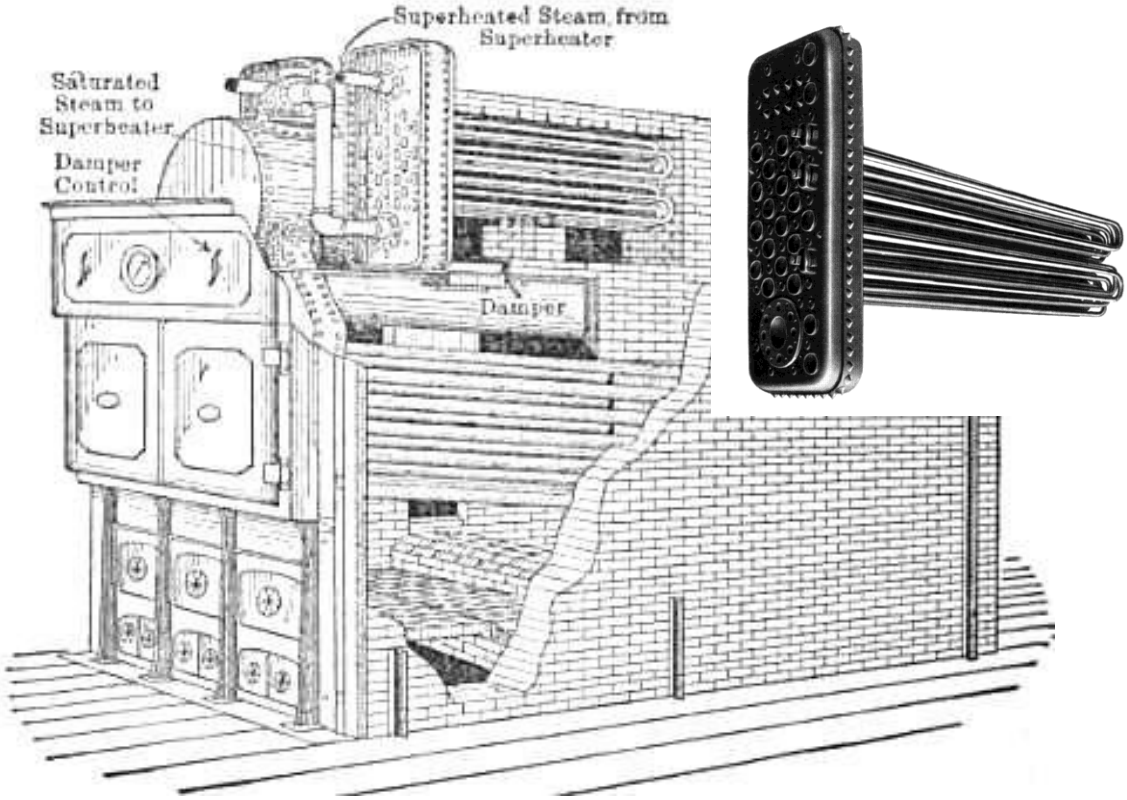
Steam in contact with the surface of the water at 150 psig has a temperature of 365 degrees Fahrenheit. Steam in contact with the water at 2500 psig has a temperature of 668 degrees Fahrenheit. By passing the steam through a set of superheater tubes, steam can be heated to temperatures of 1000 degrees or higher. Steam is superheated to increase the economy in operating a powerplant. It maximizes the BTU usage from each pound of fuel delivered to the furnace. The limit on superheat temperature is the ability of the superheater tube metal to withstand that temperature. In recent years, most manufacturers have settled on 1000 degrees as an upper limit. Though higher temperatures are possible, the increase in maintenance eliminates the thermal advantage.



Superheater on B & W Longitudinal Drum Boiler



B& W Longitudinal Drum Boiler with superheater



Heine Boiler with superheater

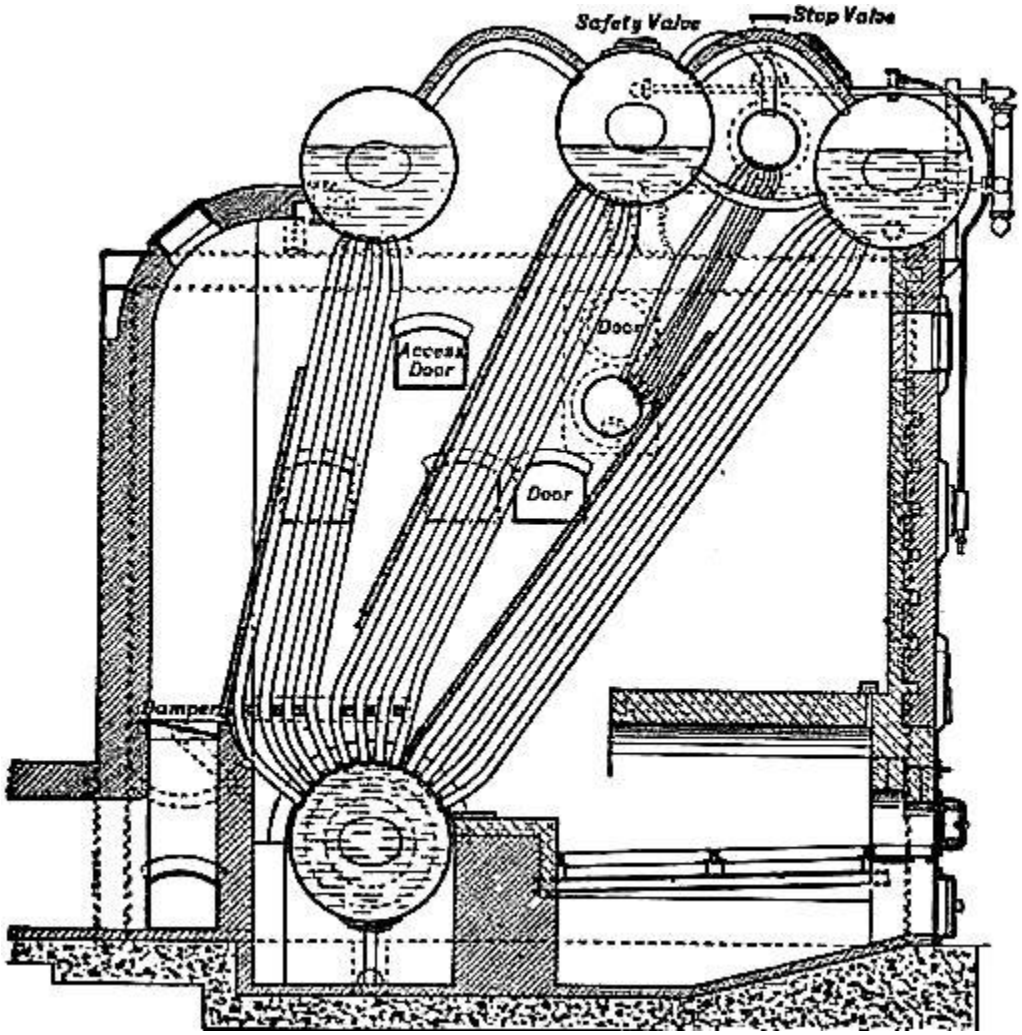
Why Steam is superheated:

1. Superheating reduces the amount of steam needed by a turbine because each pound of steam contains more heat.

2. Superheating reduces condensation in steam lines because superheated steam contains no moisture. The steam must drop to the saturation temperature at its corresponding pressure before droplets of moisture will form.

3. Steam turbine blade erosion from wet droplets hitting the blades is eliminated in all stages of the turbine where the steam is superheated.

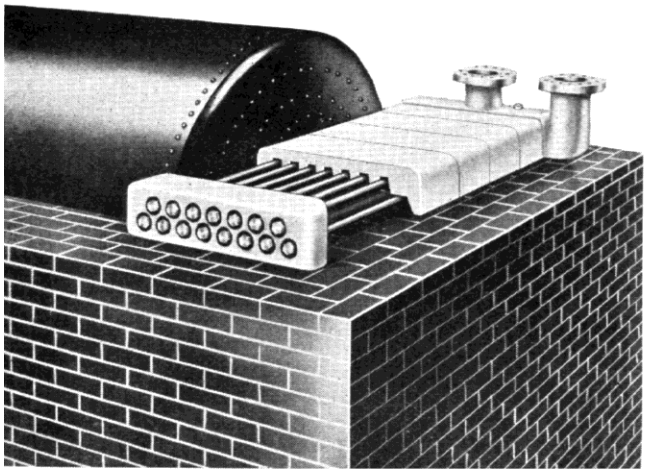
4. The mechanical horsepower output of the turbine is increased by superheating the steam. In the case of electrical generating plants, more kilowatts of electricity can be generated for each lb. of fuel burned. All large fossil fuel electrical generating plants use superheaters. Fossil fuels are coal, oil, and gas.



Stirling Boiler with Superheater in between 1st and 2nd pass

Important points to remember about superheaters are:

1. The amount of steam needed to run the turbine is decreased 1% for each 10 degrees of superheat.

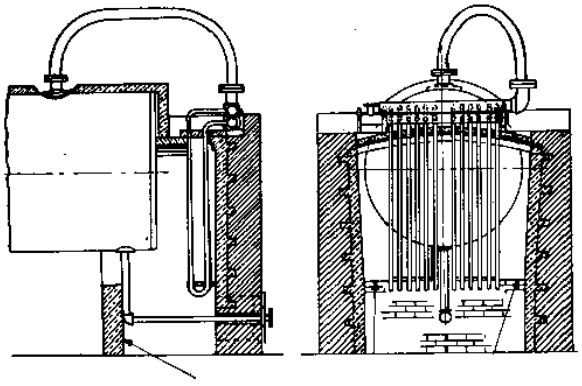


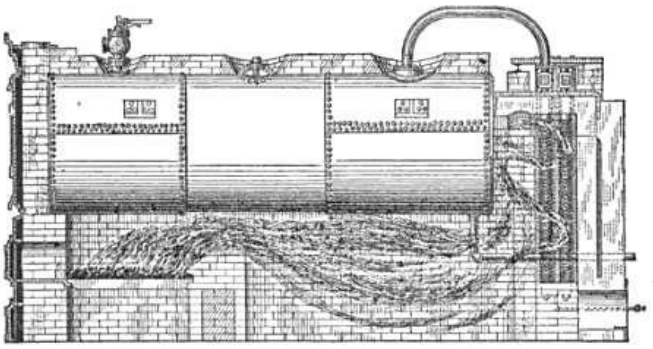
Superheater on the end of an HRT Boiler

2. Superheater tubes are made of carbon steel for temperatures up to 950 degrees Fahrenheit. Chromium alloys such as chrome-nickel and chrome-molybdenum are used for higher temperatures.

3. Pressure from the boiler is higher than that in the superheater due to the pressure drop from the steam passing through the restriction presented by the many rows of superheater tubes.

4. The safety valve on the superheater must open first and close last to keep steam flowing through the superheater and protect it from overheating.



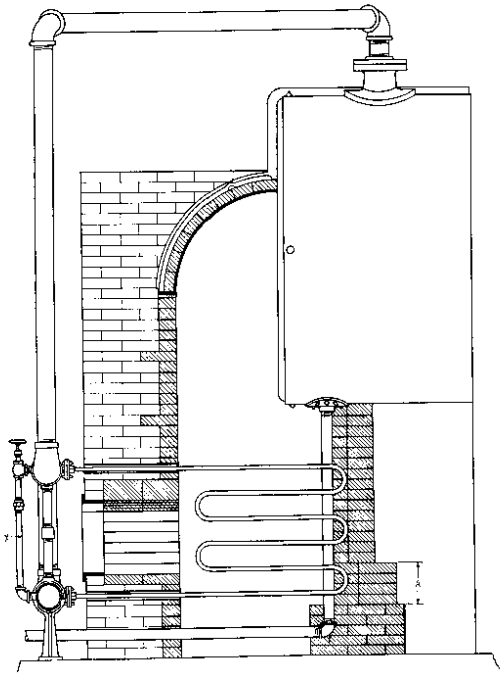


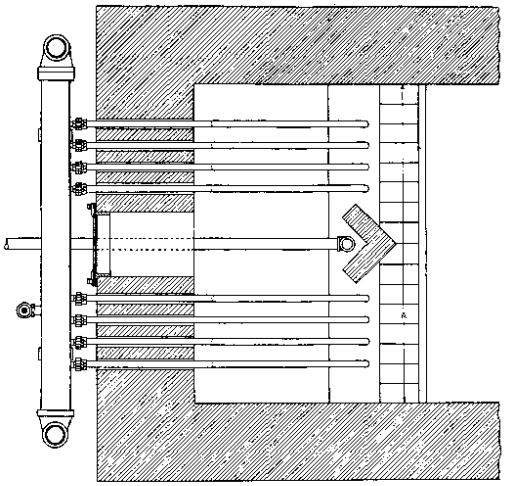
HRT Boilers with Superheaters

5. Superheaters are also classified as being drainable or non-drainable.

Superheaters with tubes that hang down such as pendent superheaters are non-drainable Pendent superheaters with round tubes in rows that resemble flat plates are known as platen superheaters. These superheaters are also non-drainable.

Platen Superheaters on modern utility boiler





Superheater on HRT Boiler with headers on the bottom that are drainable. Note the V-wall of brickwork protecting the blowdown pipe.

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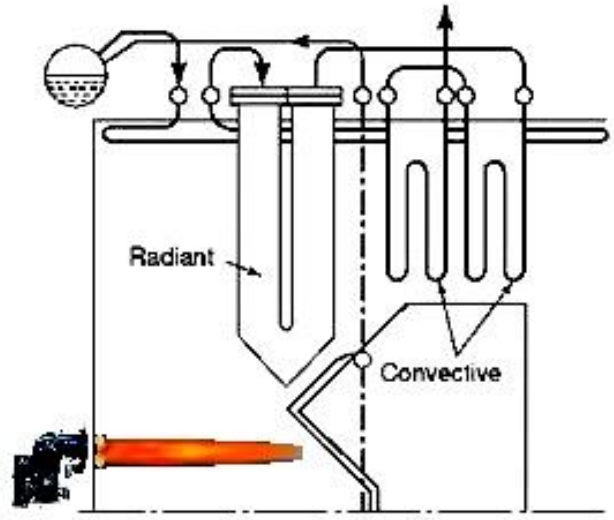
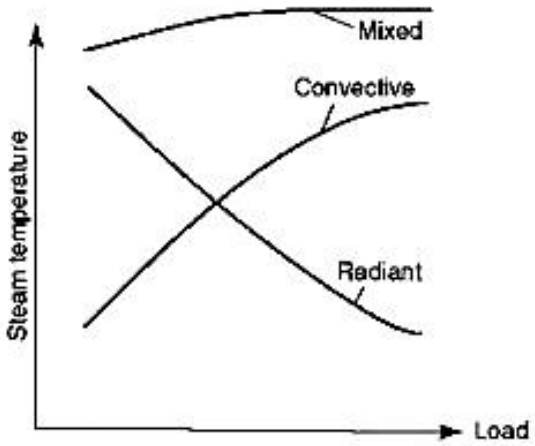




6. Superheaters are classified as either radiant or convection. Radiant superheaters are in the "eye" of the fire. Radiant waves of energy from the light generated by the fire superheat the steam. In a convection superheater, the steam is superheated by the hot convection flue gasses passing over the superheater tubes.

7. As the load increases in a radiant superheater, the superheat temperature goes down. The steam flow through the tubes increases but the brightness of the fire does not get that much brighter, so the steam flow cools the tubes and decreases the superheat.

8. As the load increases on a convection superheater, the superheat temperature goes up. Flue gas flow around the tubes is greater than the steam flowing through the tube's ability to cool, so superheat is increased.

9. If the feedwater temperature were to increase as the burner fired at a steady rate, the superheat would go down. More steam will be generated in the boiler because of the higher feedwater temperature. Since more steam is passing through the tubes while the firing rate is steady, the net effect is to lower the superheat temperature.

10. Superheater tubes are usually plain tubes 2 inches in diameter, with a 1 inch space between tubes.

11. Modern superheaters use bare tubes.

12. The superheater depends upon steam passing through the tubes to keep the tubes from burning up. Before the boiler is generating steam, some method must be provided to protect the superheater.

Ways of protecting the superheater during start-up:

1. Flood the superheater with water. This was done in early installations to protect the superheater metal. The method fell out of favor due to the scale buildup inside the superheater leading to early tube failure.

2. Bypassing the flue gas around the superheater.

3. Slowly firing the burners with superheater vents or drains wide open. Thermocouples can be welded onto the superheater tubes to show the Operator the temperature of the superheater metal.

4. Running steam from an outside source through the superheater until the boiler starts making steam.

How the temperature of the superheat is controlled:

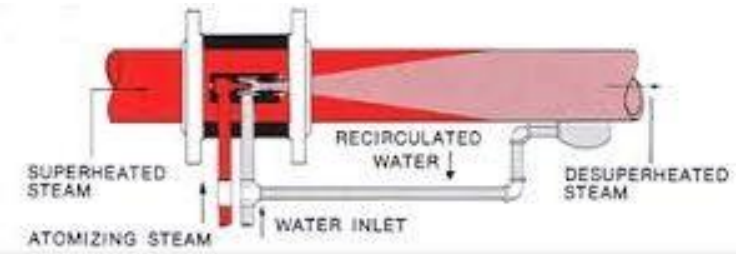
1. Bypass dampers that force the flow of flue gasses around the superheater.

2. Tilting burners. Tilting the burners up will generate more superheat. Tilting the burners down will generate less superheat.

3. Using radiant and convection superheaters in series will tend to level the superheat temperature due to their differing characteristics.

4. Splitting the furnace with baffles and using multiple burners will allow burners on different sides to be used, varying the superheat.

5. Using excess air above the burners to decrease the amount of steam generated and increasing superheat temperature by having the hotter gasses travelling across the superheater tubes.



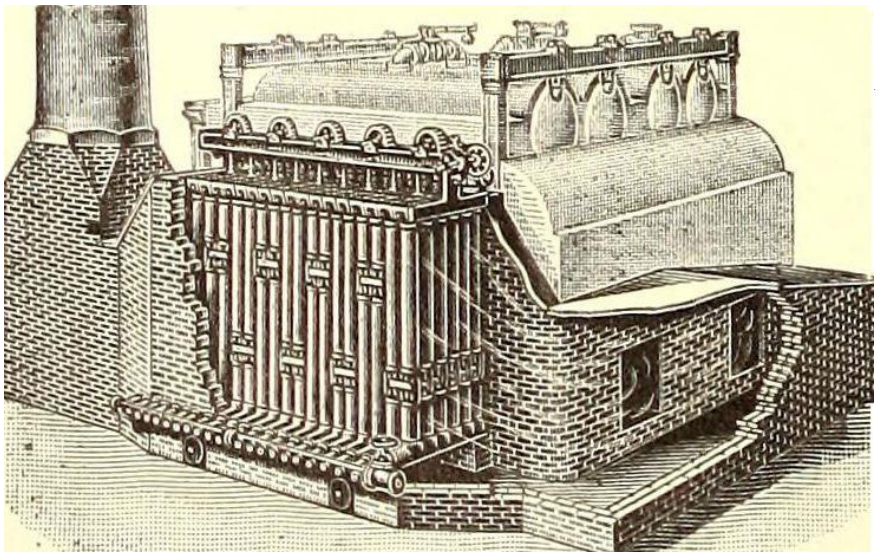
6. Desuperheaters can be used between radiant and convection superheaters to decrease the superheat temperature. A desuperheater can spray feedwater in the form of a mist to cool the steam, or the superheater tubes can run back through the drum of the boiler to desuperheat the steam.

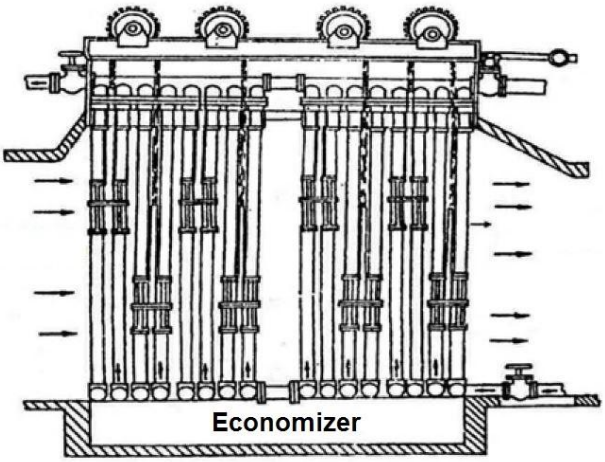
7. If the boiler tubes get dirty the superheat temperature of a convection superheater will go up because the flue gasses will be hotter. If this occurs the boiler tubes need to be cleaned.

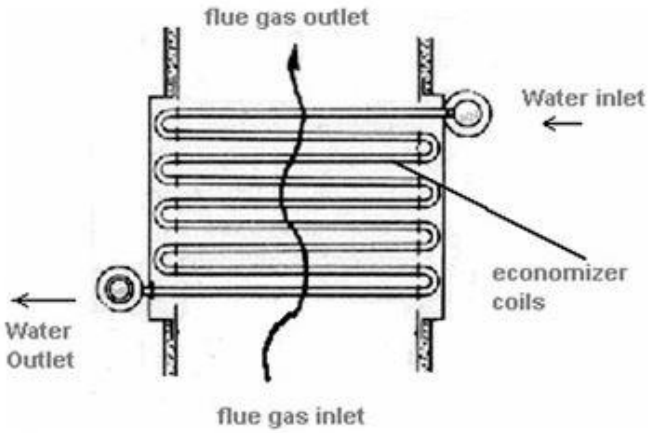
ECONOMIZERS

Whenever you operate a boiler, you want to get the maximum amount of heat from the fuel into the steam generated. The greatest loss of heat in the fuel occurs after the flue gasses have finished passing over the heating surface of the boiler and travel out the stack. If you could reclaim some of this heat, you would not need to burn as much fuel, thus saving money.

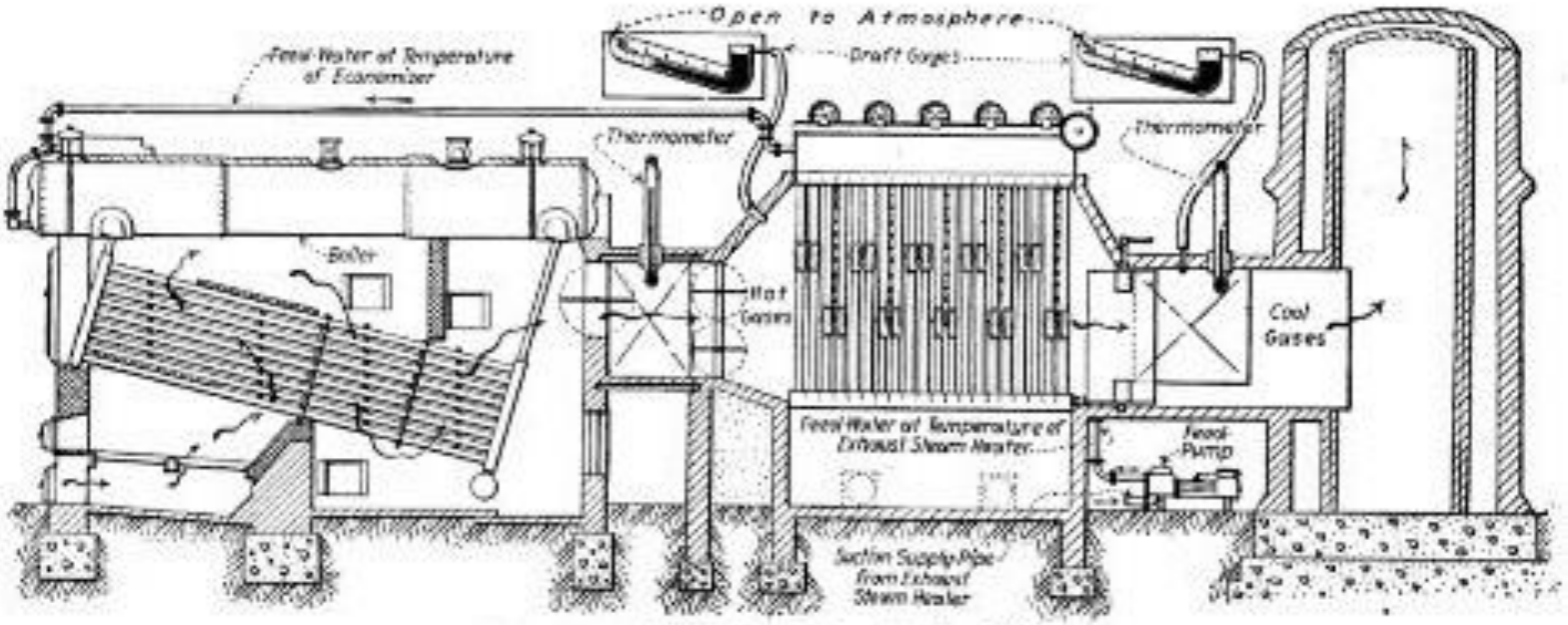
Important points to remember about economizers are:







1. The counterflow principle is used to get the maximum feedwater temperature rise in the space provided. By having the water entering the economizer at the coldest end, the hottest flue gasses are in contact with the warmest water and the cooler flue gasses are in contact with the coldest water.



A Side By-Pass Economizer Installation.

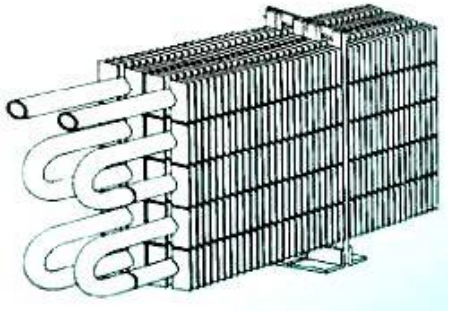
2. The economizer can save 1% of the fuel burned for each 11 degrees of feedwater heating.

3. The limit for the decrease in the temperature of the flue gas leaving the economizer cannot be lower than the temperature of the incoming feedwater.

4. The feedwater can be heated up to the saturated temperature of the water in the boiler and steam can be generated in the economizer. Such economizers are called steaming economizers.

5. Economizers are either integral or separate. Integral economizers are built as part of the boiler and are found inside the boiler casing. Separate economizers are complete units mounted outside the boiler casing.

6. Early economizers were made of cast iron but economizers today use steel tubes. The steel tubes can have cast iron gilled rings around the tube for corrosion resistance and to extend the surface of the tubes for better efficiency.

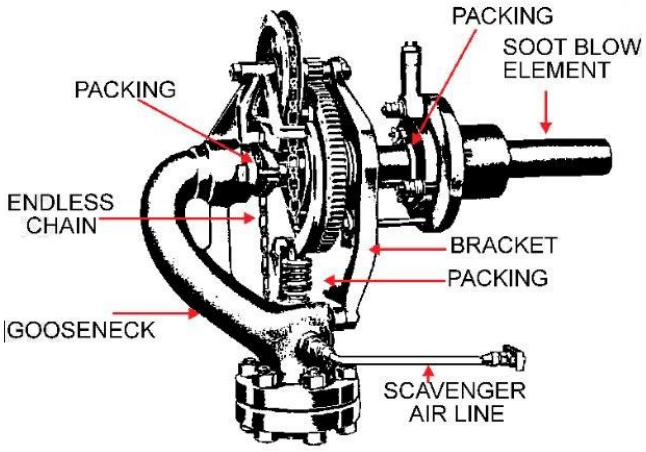


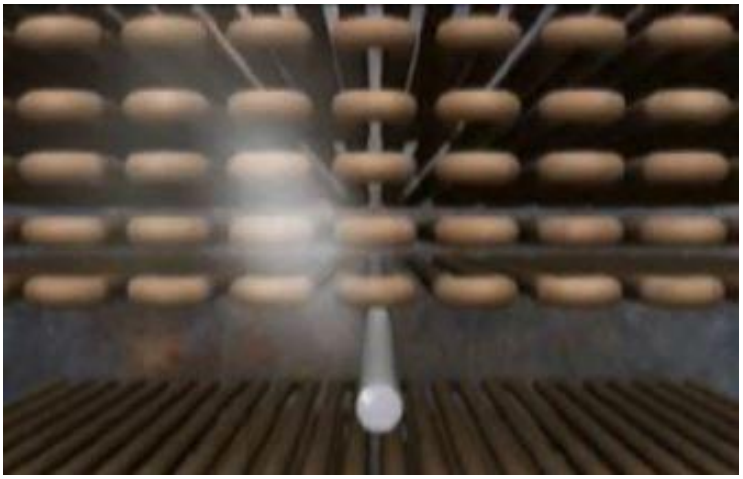
7. Cast iron had the advantage of resistance to corrosion and less draft loss due to the widely spaced four inch tubes. The code limits cast iron economizers to 250 P.S.I. or less which prevents their use on higher pressure boilers.

8. Steel tubes must use deaerated water to prevent rusting on the inside of the tube. The temperature of the feedwater must not be less than 125 degrees Fahrenheit or else moisture may condense on the outside of the tubes and cause rusting. Economizers should not lower the outlet temperature of the flue gas below the dewpoint. If you set a glass of ice water out on a hot humid day you will see beads of water forming on the outside of the glass. The ice inside the glass has cooled the outside enough to condense the moisture in the air on the surface of the glass. The same thing can happen on the surface of the economizer. Flue gasses condensing out on the tubes of the economizer contain sulfur. Sulfur combines with water to form sulfurous acid (H2S03) which will eat the metal of the economizer and all metal parts downstream of the economizer.

An example of lowering the dewpoint is the modern high efficiency condensing gas furnaces used in the home. They condense the flue gas into acid that can eat the lining of the furnace. Stainless steel and plastic are used to prevent corrosion.

9. Steel tube wall thickness is less for steel than cast iron for the same strength. This allows better heat transfer and more tubes can be placed in a smaller area than cast iron so space can be saved.

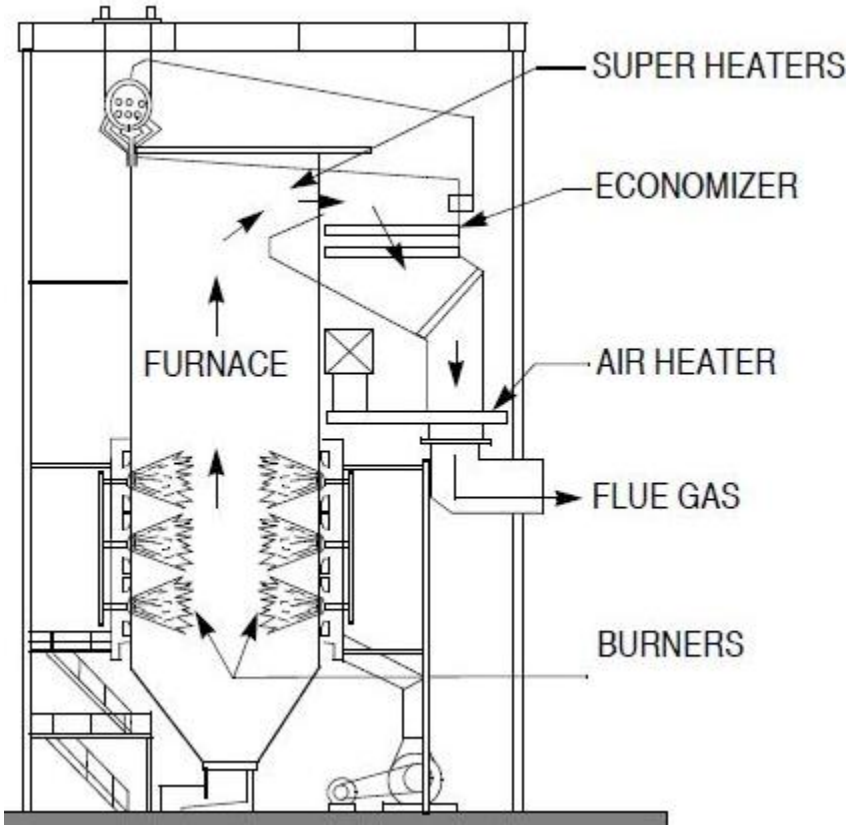




10. Economizers must be kept clean of soot and flyash if efficiency is to be kept high. During operation, economizers are kept clean by using sootblowers and movable scrapers. Water washing is used when the boiler and economizer are shut down to clean the economizer on the fire side.

11. If the economizer can be valved off where it enters the boiler then a safety valve must be installed. If the stop valve was closed and the fire started in the boiler, the check valve on the feedwater line would trap the water inside the economizer and a tube rupture would result.

12. One hazard in operating an economizer is that the economizer can overheat on start-up or during a banked condition when hot flue gasses are traveling past the economizer but no feedwater is being used by the boiler. A recirculating line hooked to the feedwater pump is used to circulate the water in the boiler through the economizer to keep the economizer cool during start-up. If the economizer had no recirculating line, the economizer may have to be blown down to keep it from overheating.

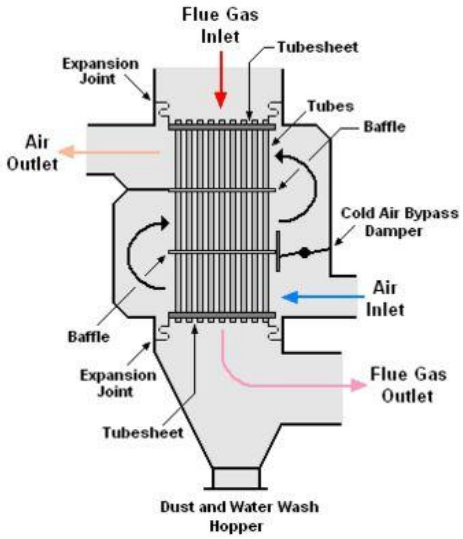


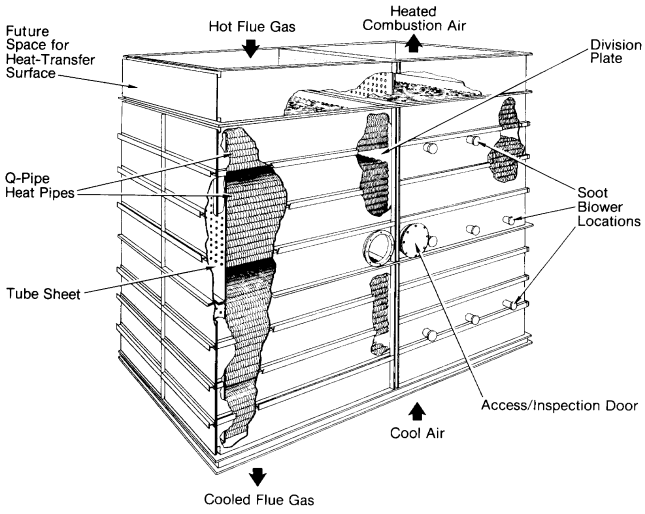
13. In order to reclaim this heat, economizers and air preheaters are used. If both an economizer and an air preheater are used, Economizers are always placed closest to the boiler. An economizer heats the incoming feedwater to the boiler by running the feedwater back and forth through tubes in the path of the flue gas.

14. Economizer tubes can freeze in the winter in idle boilers. Remote thermometers with low temperature alarms should be installed in the control room and the idle boiler started to warm the economizer back up.

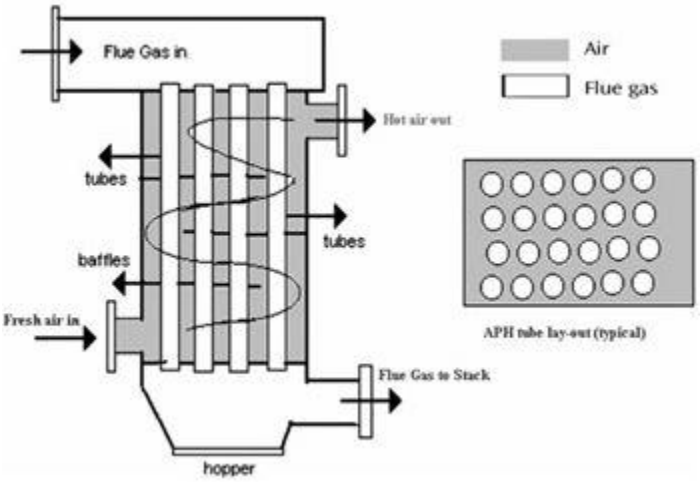
AIR PREHEATERS

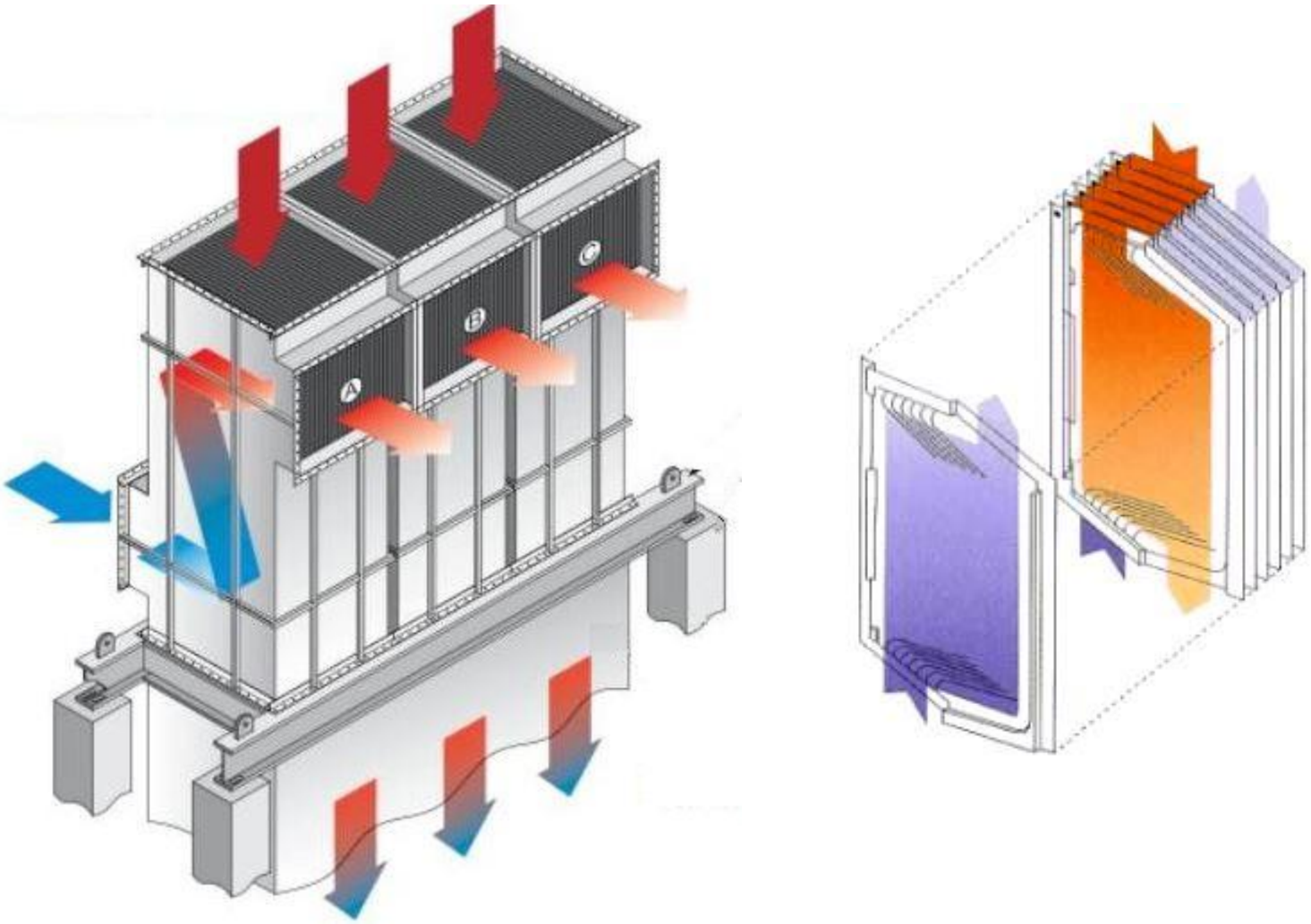
Air preheaters are used to recapture heat that would otherwise go out the stack as a waste. Air preheaters use the outgoing flue gas to preheat the incoming combustion air. There are three basic types of air preheaters, the tubular type, the plate type and the regenerative type. The regenerative type is also known as the Ljungstrom type after its inventor. Air preheaters improve combustion, increase the amount of steam that the boiler can produce from each pound of fuel, and allow the burning of lower grades of fuel than might otherwise be possible.



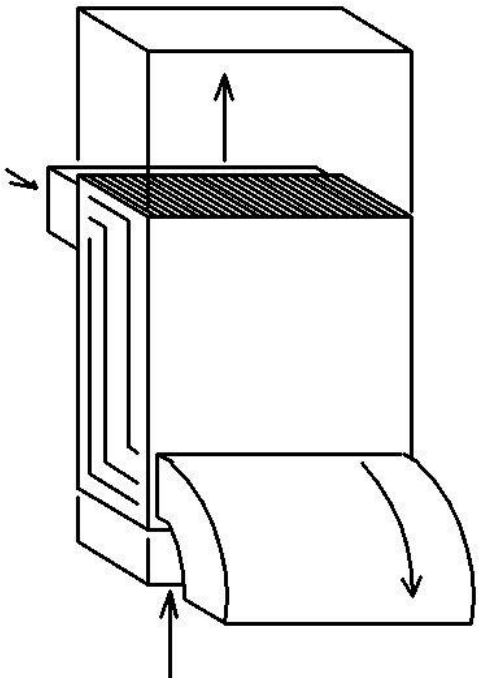


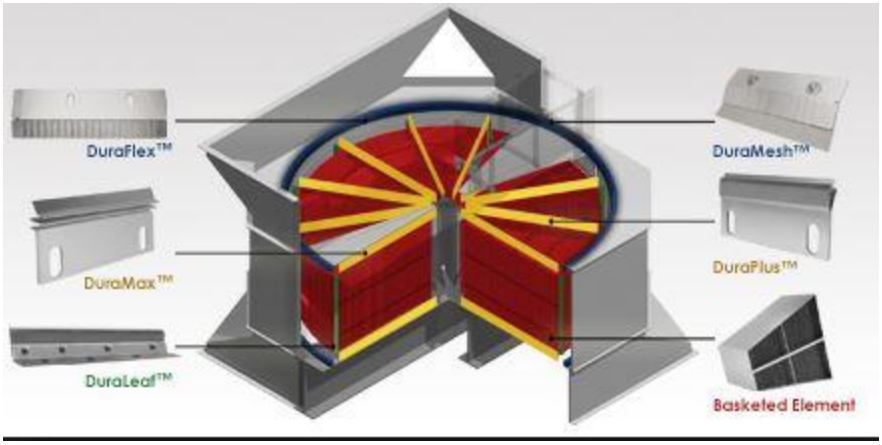
In the tubular type, the flue gas goes through the tubes and the air is sent around baffles at an angle to the tubes. This allows the tubes to be cleaned with a circular brush to remove carbon and flyash. The air bypass dampers are used to prevent the incoming combustion air from being too hot, and to prevent the flue gasses from cooling down to the dewpoint. Tubes are usually 2 1/2 inches in diameter and 45 feet in length.

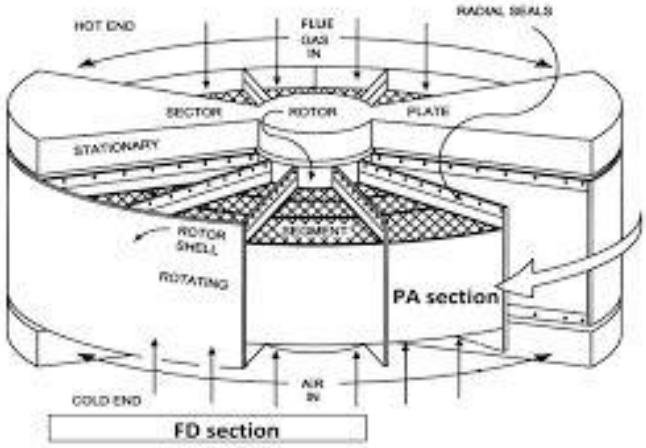




In the plate type, a steel casing encloses plates that separate the air coming in on one side of the plate from the flue gas travelling in the opposite direction on the other side of the plate. The flue gas will usually travel in a straight path from the bottom straight out the top in one pass in an effort to keep soot and flyash adhesion to a minimum. The air will travel in either a straight path or will go around baffles to increase the heat recovered. Spacing of the plates on the gas side is 1/2 to 1 1/2 inches; on the air side plate spacing is 1/2 to 3/4 inches







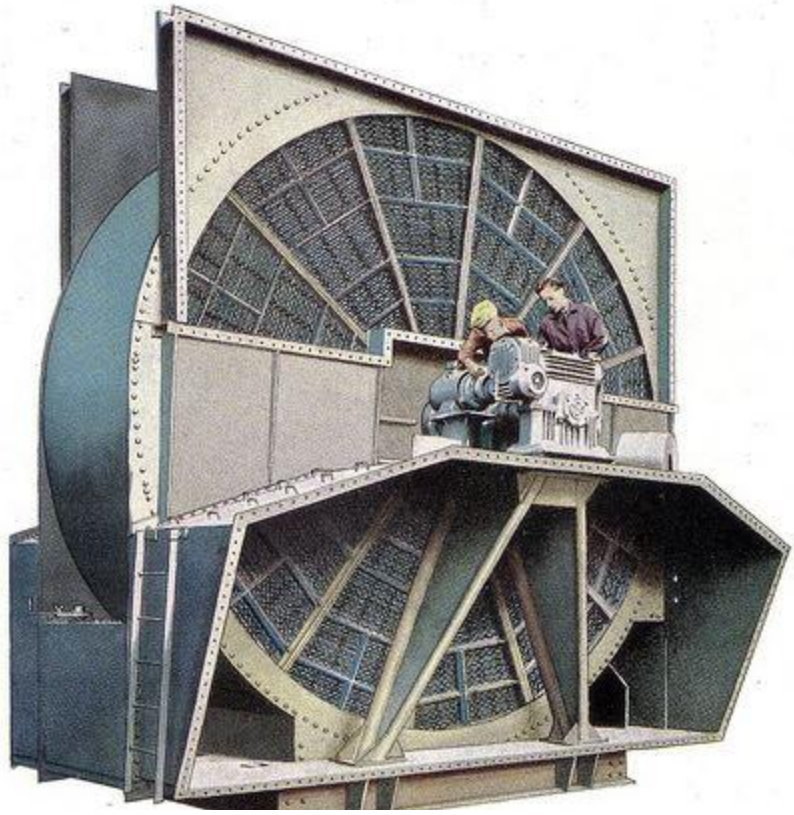
In the regenerative type, a circular grid of convoluted plates make up the rotor. In some types the rotor revolves with the stationary air duct and stationary flue gas duct next to each other. The plates pick up the heat from the flue gas and then immediately transfer that heat to the air as the rotor revolves through the air duct. In the other type of regenerative air preheater, the rotor is stationary and the duct hoods for the incoming air revolve above and below the rotor. Seals keep the air from leaking into the flue gas.

Important points to remember about air preheaters

1. When an air preheater is used, an induced draft fan becomes a necessity due to the draft loss through the air preheater.

2. Preheated air temperature limits on stoker fired installations vary from 200 degrees to 450 degrees, with 300 degrees Fahrenheit an accepted average.

3. Preheated air for pulverized coal has a temperature limit of 500 to 600 degrees Fahrenheit.



Large Vertical Regenerative Air Preheater

4. Air preheaters can be several stories tall. They can be installed in a horizontal or vertical position

5. For every 100 degrees of preheated air, there is a 5% to 10% fuel savings.

6. Sulfur in flue gas raises the dewpoint at which acid will condense out on preheater surfaces. This can occur when the metal temperature is as high as 300 degrees and the exit gas temperature is 500 degrees Fahrenheit

7. One inch height of regenerative preheater equals 1 foot height of plate type preheater and 2 foot height of tubular preheater.

8. Sootblowers are used to clean the air preheater while in service. Water washing is used when the boiler is out of service.

Sootblower on Regenerative Air Preheater

Chapter 7 questions

1. What are the two types of superheaters?
2. What is the diameter of most superheater tubes?
3. What is the highest temperature of steam at the outlet of the superheater? Why?
4. What are superheater tubes constructed of?
5. Are superheater tubes bare or do they use extended surface tubes?
6. What is the load characteristic of a radiant superheater?
7. What is the load characteristic of a convection superheater?
8. How do you protect a superheater on start-up?
9. How do you control the outlet temperature of a superheater?
10. Do economizers use parallel flow or counter flow? Why?
11. How much fuel can an economizer save for each eleven degrees feedwater heating?
12. What is the difference between an integral and a separate economizer?
13. Why are steel tube economizers used today?
14. What will happen if the economizer cools the flue gasses too much?
15. What are the three basic types of air preheaters?
16. Why does the flue gas in the tubular air preheater go through the tubes and not around the tubes?
17. What is the space between the plates on the gas side of a plate type preheater?
18. How much fuel can be saved for each 100 degrees of air preheating?
19. On the regenerative type preheater, does the rotor always turn? Explain.

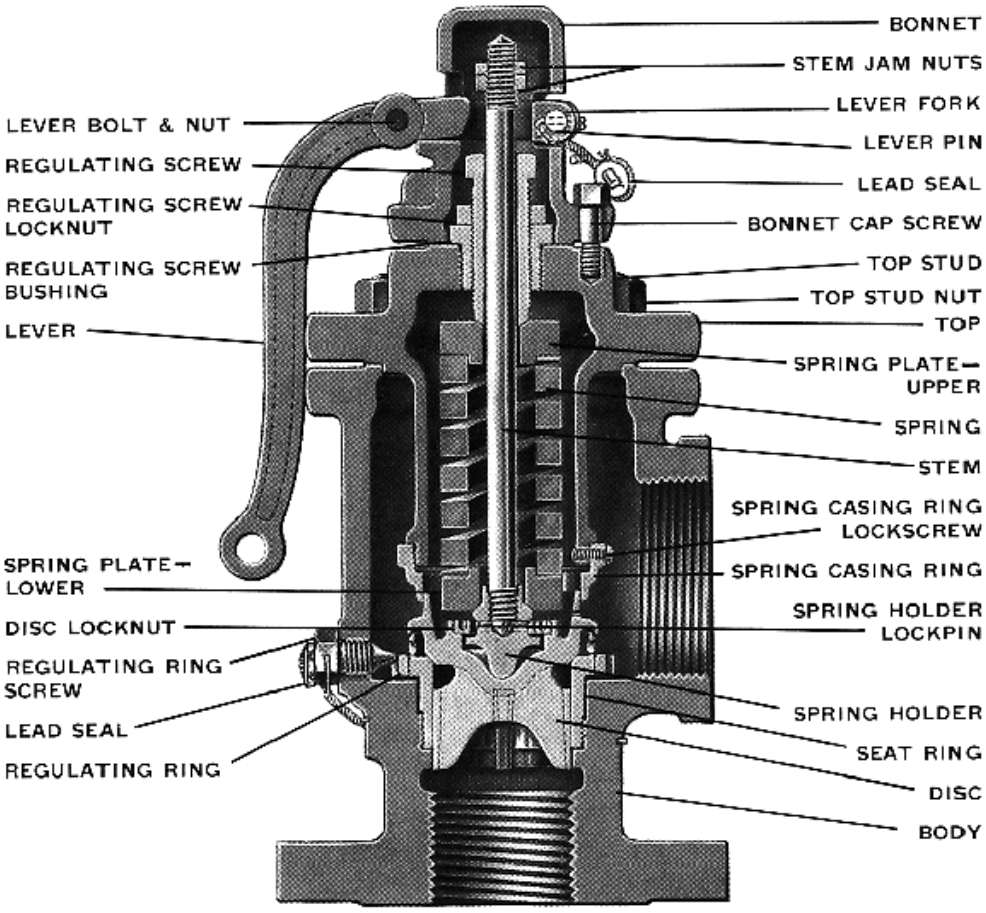
Welding tubes on an economizer header. Note the counterbores to allow a full penetration of the weld metal (Courtesy Optimus Industries)

Chapter 8

SAFETY VALVES

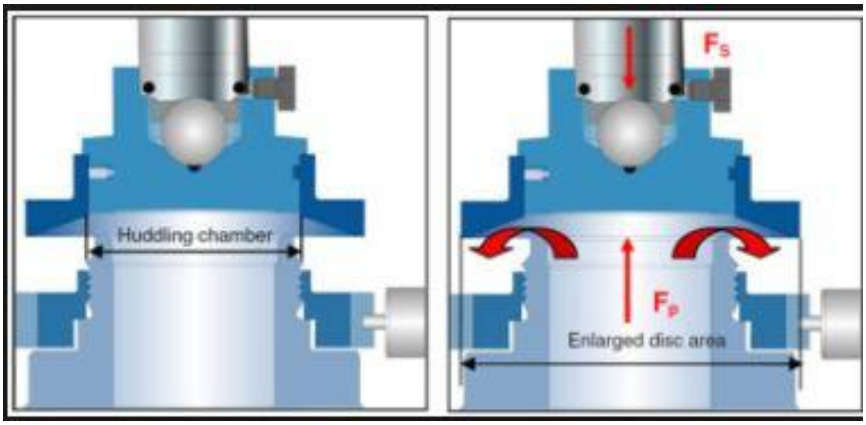
Safety Valves are devices attached directly to the boiler for release of excess pressure.

SAFETY VALVES

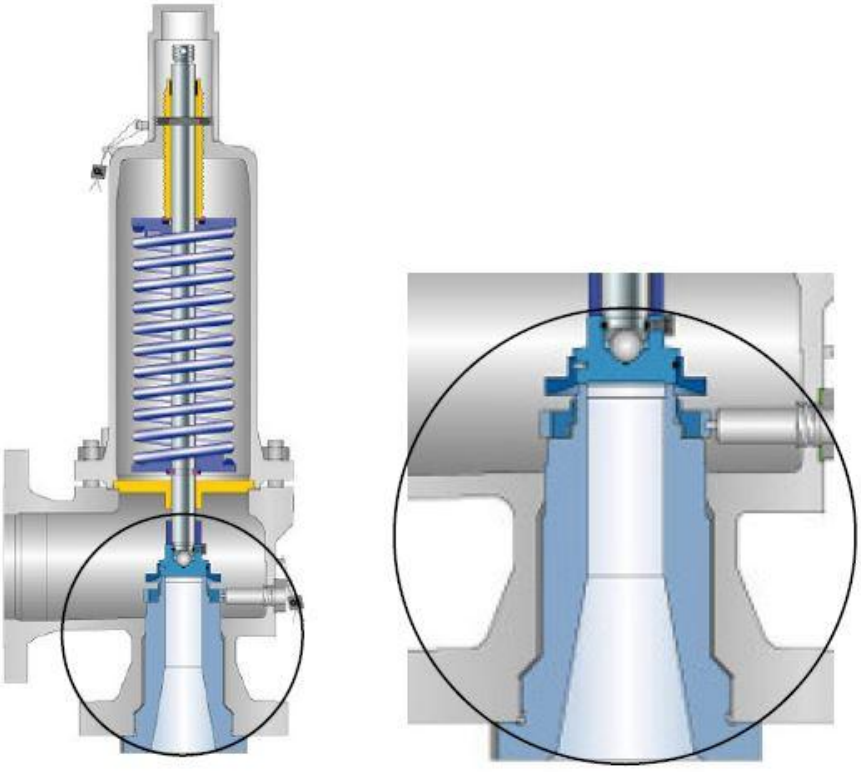


The safety valve is the most important valve on the boiler. The purpose of the safety valve is to relieve pressure on the boiler if the pressure exceeds the maximum allowable working pressure on the boiler or the spring setting on the safety valve, whichever is lower. The ASME Code is very specific about the rules that must be followed in installing and maintaining safety valves. It is critical that Boiler Operators know these rules for the safety of the Operator and others around the boiler room.

Important points to remember about safety valves are:

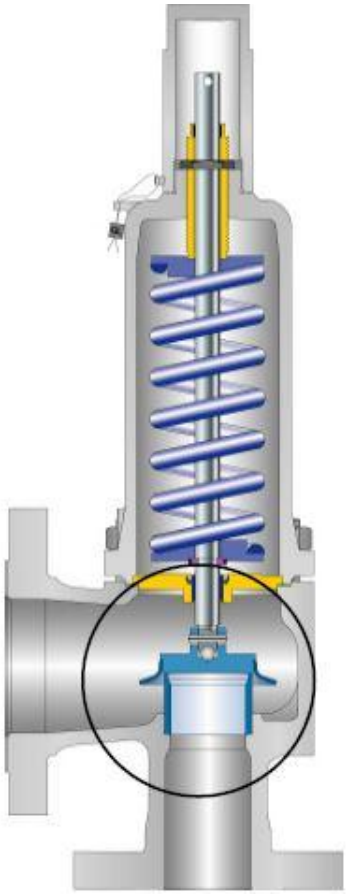


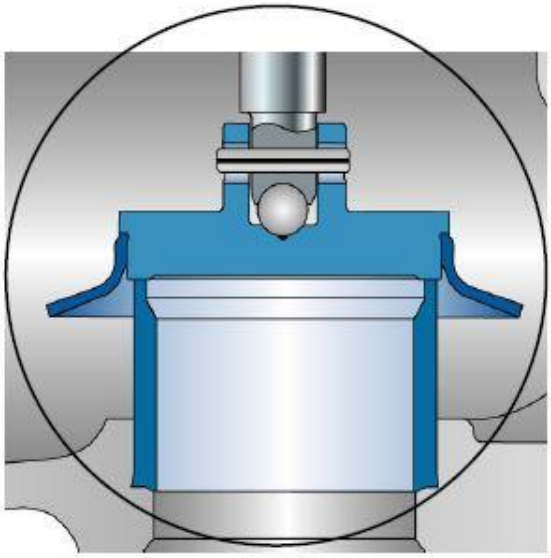
1. Modern safety valves are known as "pop" safety valves. They are spring loaded and fall into two general categories, the "huddling chamber" type and the nozzle type. Both use the principle of the downward reaction force of the steam to pop the valve wide open as soon as the valve begins to lift. As the steam begins to escape into an area of the valve known as the huddling chamber, the increase in area builds the force necessary to pop open the valve when overpressure occurs. Popping helps prevent the wiredrawing and leakage that occurs when the valve opens slowly. As the steam hits the adjustable ring of the nozzle type, the downward reaction force pops the valve open.



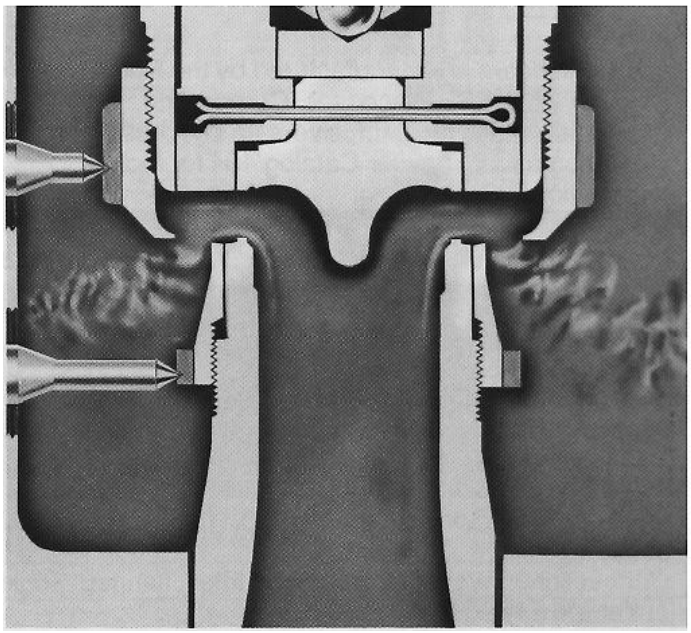
The valve inlet (or approach channel) of a nozzle type safety valve design can be either a full-nozzle or a semi-nozzle type. A full-nozzle design has the entire 'wetted' inlet tract formed from one piece. The approach channel is the only part of the safety valve that is exposed to the process fluid during normal operation, other than the disc, unless the valve is discharging.

Full-nozzles are usually incorporated in safety valves designed for process and high pressure applications, especially when the fluid is corrosive. Together with a disc in stainless steel, all permanently wetted parts have excellent corrosion resistance. In corrosive process applications selection of a carbon steel body material is possible. A full nozzle is typically removable and can either be replaced or repaired outside of the valve body. Full nozzle designs require more machining and material and are less cost effective than semi-nozzle designs. The full-nozzle type is good for all pressure ranges

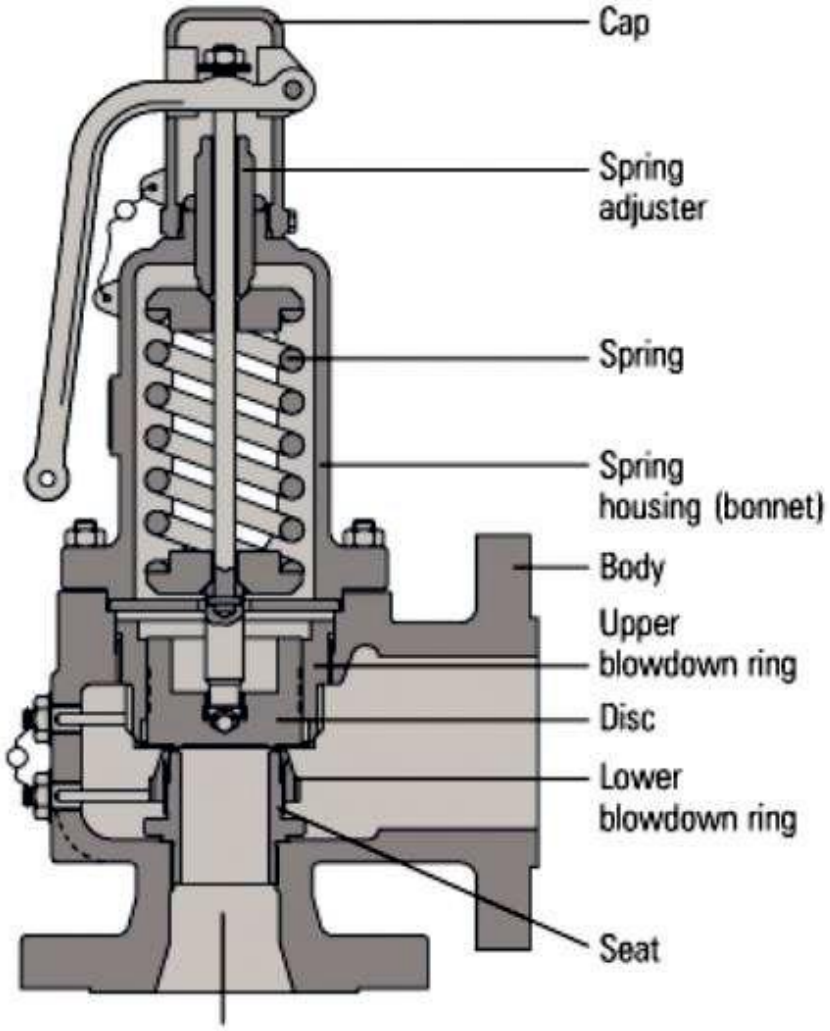




Conversely, the semi-nozzle design consists of a seating ring fitted into the body, the top of which forms the seat of the valve. The advantage of this arrangement is that the seat can easily be replaced, without replacing the whole inlet. The valve body will be permanently in contact with the medium. .A carbon steel body material can be selected for non corrosive applications. A stainless steel body material should be selected for corrosive process applications. In most cases full bore designs with maximum capacity relative to the valve size. A semi-nozzle can typically not be removed. Repair is possible inside of the valve body with lapping tools. To repair major damages of the seat, the complete body must be taken on a lathe. A semi nozzle design requires less machining and less material than a full nozzle design in manufacture thus being more cost effective. Max set pressure is 1450 psig



The disc is held against the nozzle seat (under normal operating conditions) by the spring, which is housed in an open or closed spring housing arrangement (or bonnet) mounted on top of the body. The discs used in rapid opening (pop type) safety valves are surrounded by a shroud, disc holder or huddling chamber which helps to produce the rapid opening characteristic.

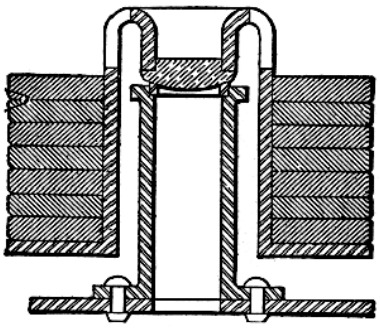


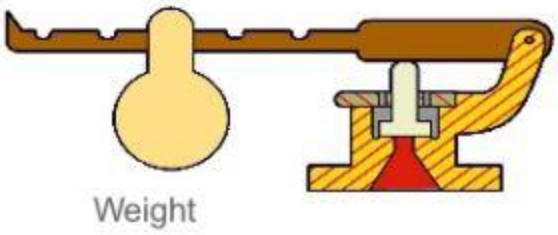
Typical ASME valve

The closing force on the disc is provided by a spring, typically made from carbon steel. The amount of compression on the spring is usually adjustable, using the spring adjuster, to alter the pressure at which the disc is lifted off its seat.

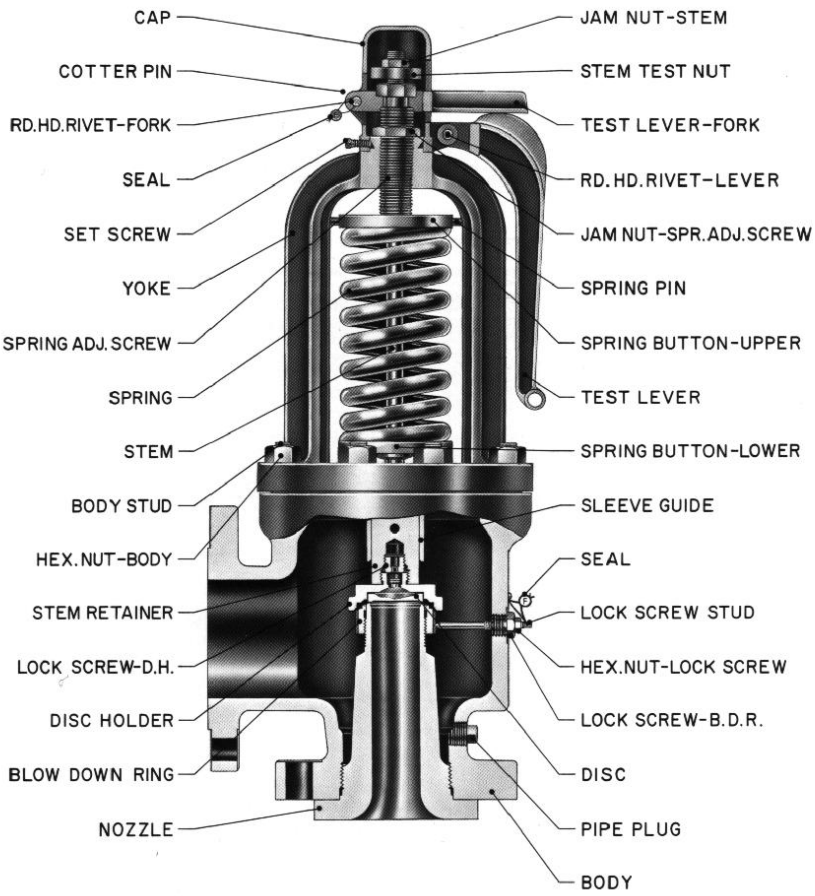
The blowdown rings found on most ASME type safety valves are used to make fine adjustments to the overpressure and blowdown values of the valves. The lower blowdown (nozzle) ring is a common feature on many valves where the tighter overpressure and blowdown requirements require a more sophisticated designed solution. The upper blowdown ring is usually factory set and essentially takes out the manufacturing tolerances which affect the geometry of the huddling chamber.

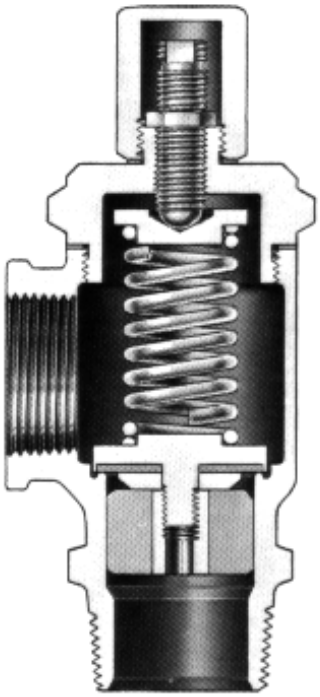
The lower blowdown ring is also factory set to achieve the appropriate code performance requirements but under certain circumstances can be altered. When the lower blowdown ring is adjusted to its top position the huddling chamber volume is such that the valve will pop rapidly, minimizing the overpressure value but correspondingly requiring a greater blowdown before the valve re-seats. When the lower blowdown ring is adjusted to its lower position there is minimal restriction in the huddling chamber and a greater overpressure will be required before the valve is fully open but the blowdown value will be reduced.





2. Obsolete safety valves were of the weight loaded lever type and were outlawed due to the ease that an unskilled Boiler Operator could alter the leverage on the weight and prevent the valve from opening when necessary. This type of valve was also more subject to leakage.





Relief Valve

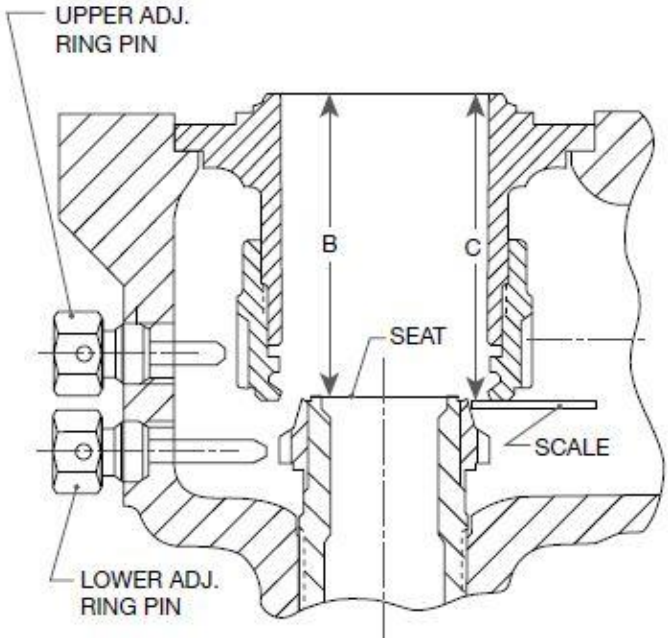
3. The difference between safety valves and relief valves is that the pressure on a safety valve must decrease below the set pressure before the valve will reseat. A relief valve will reseat at the same pressure it lifted. The difference between the popping pressure and the resetting pressure is known as safety valve blowdown or blowback. The purpose of this blowdown or blowback is to prevent the safety valve from chattering on its seat and starting to leak. All steam boilers must use safety valves. Hot water heaters are examples of pressure vessels that use relief valves.

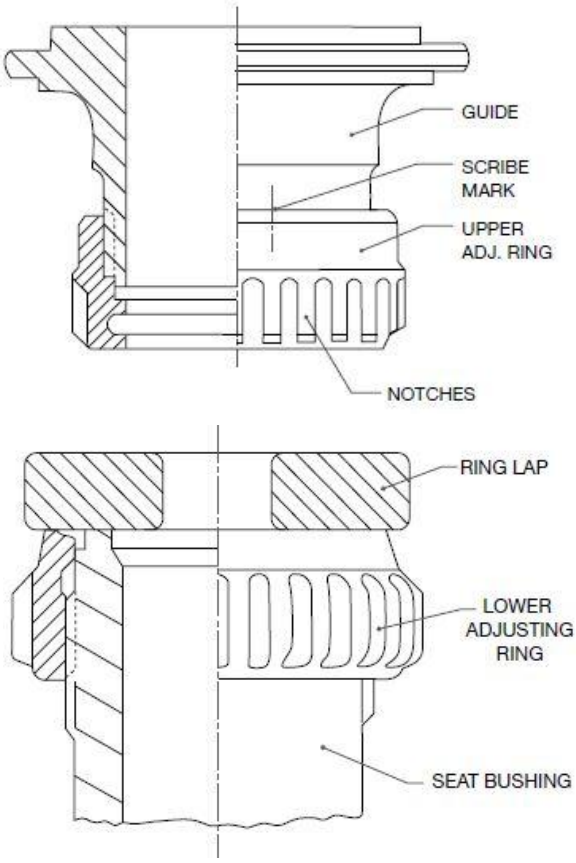
Adjusting Rings

4. The blowdown is adjusted by removing a pipe plug at the base of the safety valve and using a screwdriver or other tool with a flat blade to adjust a ring that surrounds the huddling chamber that has slots in it to fit the screwdriver. If a valve has two rings, the top ring attached to the disk is known as the blowdown ring. Turning the blowdown ring clockwise or left lowers the ring and increases the blowdown. Turning the blowdown ring counter-clockwise or to the right raises the ring and decreases the blowdown.

Start of Pop

Fully Blowing





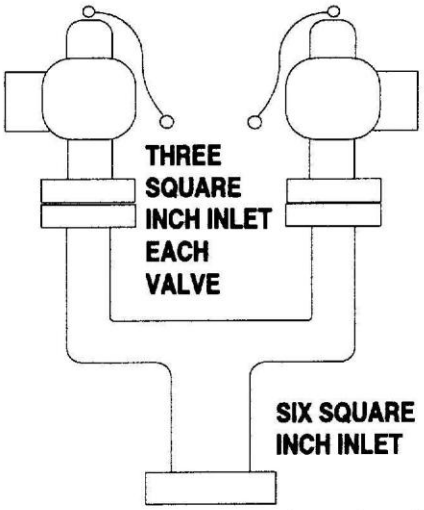
The bottom ring is attached to the valve seat and is known as the adjusting ring. Turning the adjusting ring clockwise or to the left lowers the ring and decreases the blowdown. Turning the adjusting ring counter-clockwise or to the right raises the ring and increases the blowdown.

5. The minimum blowdown on a safety valve is 2 psi. The maximum blowdown on a safety valve is 4% of the set pressure. For safety valves set at pressures between 100 psi up to and including 300 psi, the minimum blowdown cannot be less than 2%.

Let's take the example of a safety valve set at 75 psi. The safety valve in this case would reset at a pressure from 73 psi (2 psi) to 72 psi (4%). A safety valve set at 250 psi would reset at a pressure from 245 psi (2%) to 240 psi (4%).

6. A boiler that does not exceed 500 square feet of heating surface only requires one safety valve. If the heating surface exceeds 500 square feet of or if the steam generating capacity of the boiler exceeds 2000 pounds of steam per hour, then the boiler will require two or more safety valves. The heating surface of the boiler can be found on the stamp on the boiler.

7. When no more than two valves are mounted by themselves on the boiler, the smaller valve cannot be less than 50% the relieving capacity of the larger valve.



Y base for mounting twin valves. Each valve has the same steam relieving capacity

8. Twin valves mounted on a Y base must be the same size. The square inch area of the inlet to the Y must be as great or greater than the total square inch area of the inlet of the two valves.

9. Safety valves have a lifting lever to lift the disk from its seat to ensure that the valve is not sticking. There should be at least 75% of the full working pressure on the boiler before the valve is tested by lifting the handle. This to blow any dirt that might fall into the seat clear of the safety valve. Use a chain or rope over a pulley with a spring on the chain or rope to relieve any tension on the lifting lever. You can then lift the lever at a safe distance from the escaping steam.

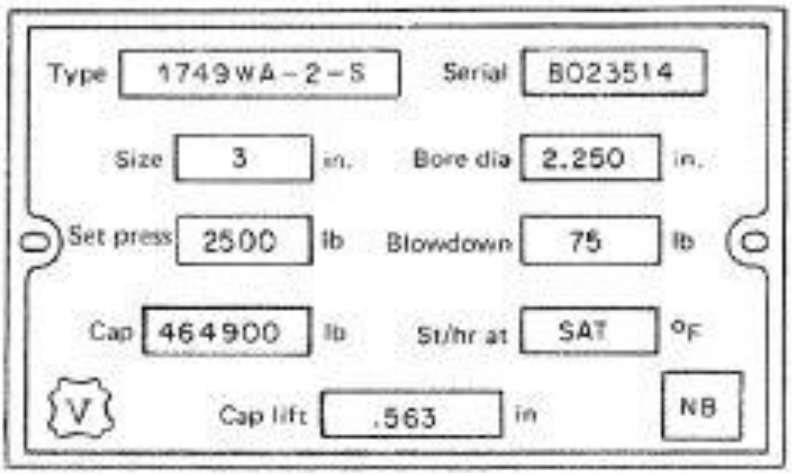
10. The safety valves must have enough relieving capacity so that when all the safety valves are blowing, the maximum allowable working pressure of the boiler cannot be exceeded by 6%. If the valves are set at less than the maximum allowable working pressure, then the pressure cannot exceed 6% above the pressure for which any valve is set. One or more safety valves on the boiler shall be set at or below the maximum allowable working pressure. If additional valves are used the highest pressure setting shall not exceed the maximum allowable working pressure by more than 3%. The complete range of pressure settings of all the saturated steam safety valves on a boiler shall not exceed 10% of the highest pressure to which any valve is set.

Now let's discuss what this portion of the Code is saying and use some examples. We'll assume that we have a boiler that has a maximum allowable working pressure of 100 psi and three safety valves. We will also assume that this boiler can generate 100,000 pounds of steam per hour. We operate the boiler at 90 psi. Each valve is rated at a relieving capacity of 40,000 pounds of steam per hour at 100 psi.

The first valve we will set at 100 psi. This fulfills the at or below maximum allowable working pressure requirement. The next valve we will set at 103 psi, which fulfills the 3% requirement. Note that the pressure from the highest setting to the lowest setting cannot exceed 10%. This means that the lowest we can set the last of our three safety valves is 93 psi. So if we set our three safety valves at 93, 100, and 103 psi, we would fulfill the 3% and 10% requirements. If we fired the boiler at its maximum firing rate with the main steam valve shut, the safety valves must not exceed 6% of the maximum allowable working pressure. Since all three valves can handle around 40,000 pounds of steam per hour, or 120,000 pounds of steam per hour total, the maximum allowable working pressure would not be exceeded.

Why not set all safety valves at 100 psi and not worry about the 3% and 10% rule? It would not be advisable to have all three valves lift at the same time and waste steam. It would also not be advisable to have the lowest valve set close to the normal pressure that we operate the boiler at; otherwise there will be a lot of nuisance popping of the valve if the normal operating pressure were exceeded in a plant where the load changes are sudden. The 93, 100, and 103 psi examples above were used just to give you the range of what the Code allows. A boiler that had a normal operating pressure lower than the maximum allowable working pressure stamped on the boiler (which is very common) might be something like this in actual practice. The boiler has a maximum allowable working pressure of 100 psi. The boiler is usually run at 90 psi and the safety valves are set at 97, 100 and 103 psi. This fulfills all the requirements of the Code and would not waste steam if the boiler pressure got too high.

Let's take another example where the maximum allowable working pressure on the boiler was once 100 psi but management decides to run at 47 psi to save money. One safety valve is set at 50 psi. The next valve cannot exceed 6% of the highest pressure to which any valve is set, therefore the highest pressure setting would be 53 psi. Note that if you lower the operating pressure on a boiler too much you are going to need bigger safety valves or more safety valves (cut a new hole in the top of the boiler) because of the increased volume of steam at the lower pressure. Safety valves have a limit on their ability to adjust spring pressure and the 10% limit was exceeded.



11. Every safety valve must have the following identifying markings in order to meet the ASME Code. These markings will either be stamped into the body of the valve or else will be on a tag securely fastened to the valve.

a. The name or trademark of the manufacturer
b. The manufacturer's design or type number
c. Pipe size of the inlet in inches
d. Seat diameter in inches
e. The pressure that it will pop at in pounds per square inch
f. The blowdown in pounds per square inch
g. The steam relieving capacity in pounds of steam per hour
h. The distance in inches that the valve disk rises above its seat when the valve is blowing at 3% over the set pressure
i. The ASME symbol which is a 4 cloverleaf design with a "V" in the center
j. The year built

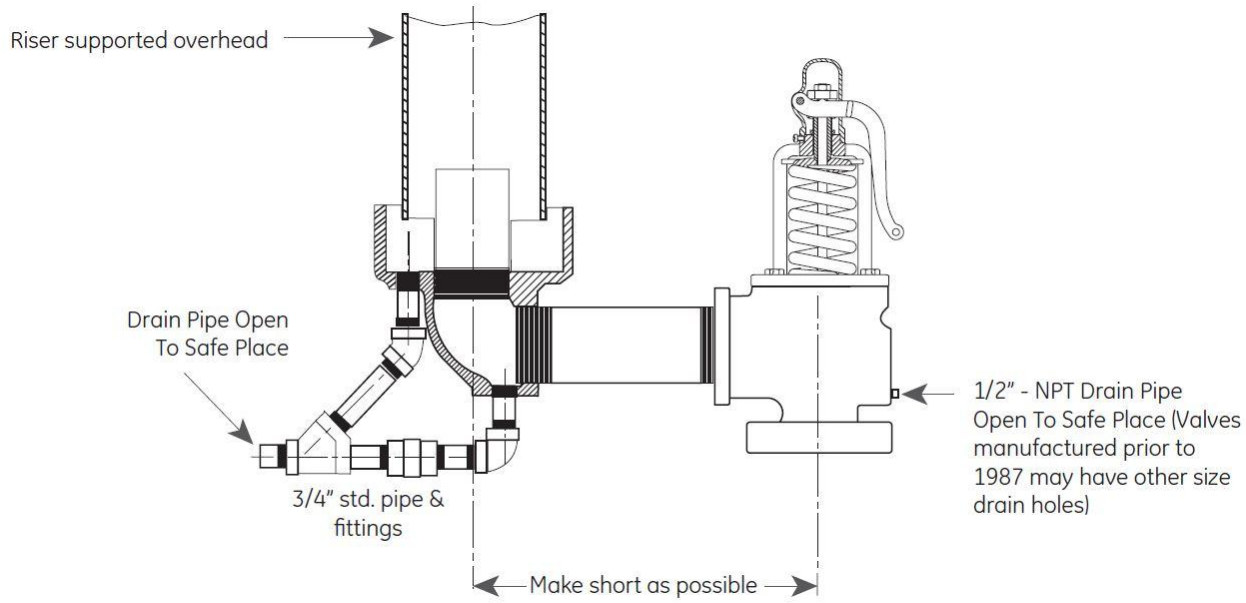
12. If the operating conditions are changed or additional heating surface added, such as waterwalls, the relieving capacity of the boiler must be increased by adding additional safety valves if necessary to meet the new conditions.

The BTU content of oil or gas is greater than coal, therefore if a coal fired boiler is changed to fire gas or oil, more safety valves would be needed because more steam will be generated.

As previously stated, if the maximum operating pressure of a boiler is lowered by the inspector because of the age of the boiler or some other factor, and new safety valves are ordered to pop at the lower pressure, more safety valves than originally installed on the boiler may be needed. The reason is that the higher the pressure, the more steam can be forced out a certain sized orifice. If that pressure is reduced, not as much steam can escape as it could at the higher pressure and the boiler could exceed the new maximum operating pressure by more than 6%.

13. No valve of any kind can be placed between the boiler and the safety valve. The safety valve must be connected directly to the top of the boiler with a nozzle that has nothing else attached to it.

14. The discharge of any safety valve will not be toward any running boards or platforms, for the safety of the Operator.

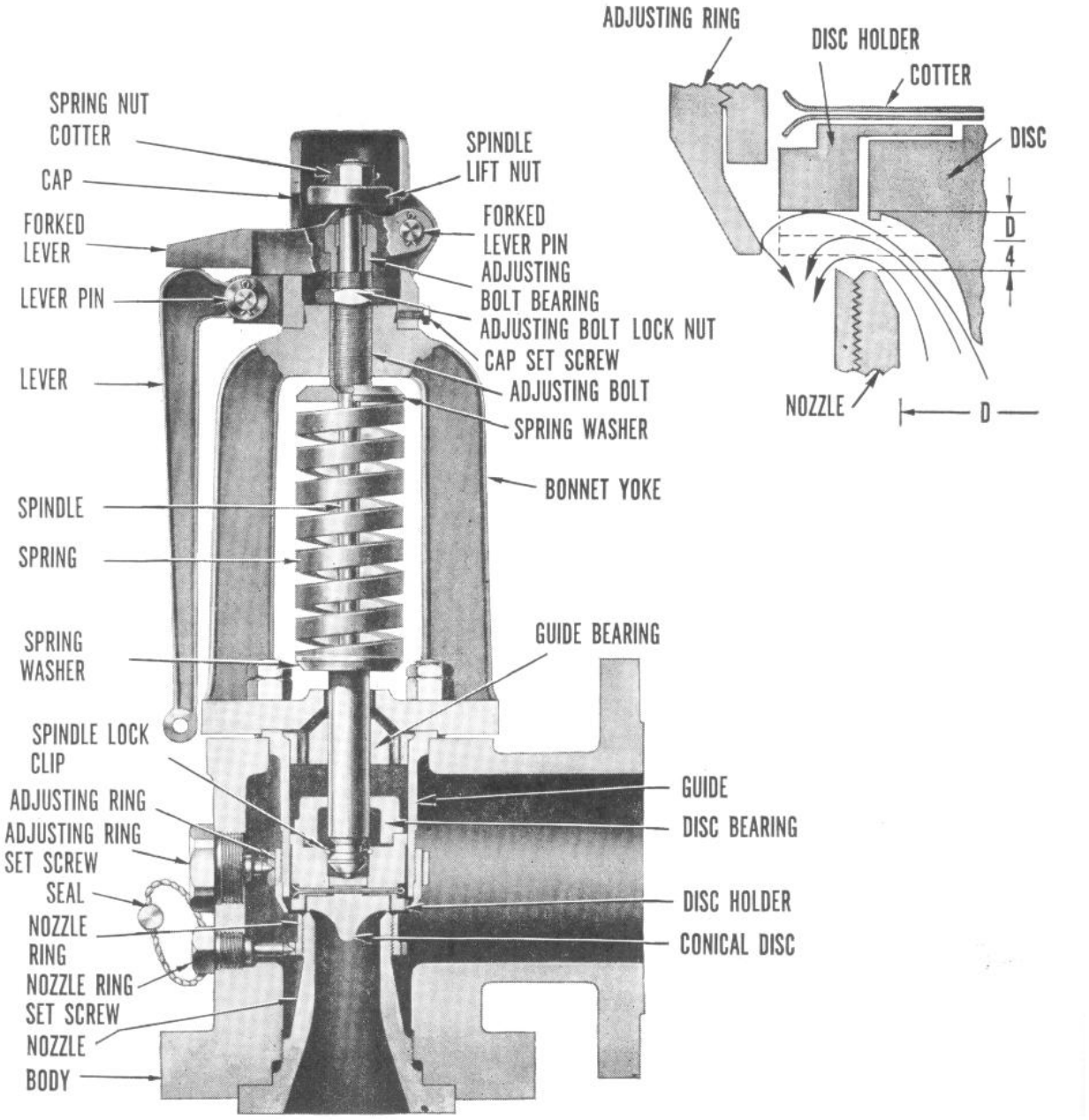

Riser supported overhead
Drain Pipe Open To Safe Place
3/4" std. pipe & fittings
1/2" - NPT Drain Pipe Open To Safe Place (Valves manufactured prior to 1987 may have other size drain holes)
Make short as possible

15. Each valve will have a drain in the body of the valve below the valve seat to drain the water that may collect. The discharge pipe from the safety valve will also have a water drain. Any valve over 2 1/2 inches inlet diameter pipe size will have a drain hole not less than 3/8 inch pipe size. The discharge pipe from the safety valve cannot put any strain on the safety valve and so it is not threaded rigidly to the outlet of the valve. The discharge pipe is secured to the building and the pipe should run a minimum of 6 feet above the roof for the safety of anyone that would be near the discharge pipe on the roof. The pipe size out the discharge outlet should increase by one pipe size for every 12 feet of pipe to prevent chattering of the safety valve due to excessive back pressure being built up in the pipe when the safety valve blows.

16. The seats of the safety valve must be made of non-corrosive material. Permissible materials include stainless steel, bronze, nickel, or monel. The seat must be from 45 degrees up to and including 90 degrees to the valve spindle.

17. Safety valves over 3 inch pipe size used for pressures over 15 psi will have a flanged inlet connection or a welding end inlet connection.

18. A safety valve used for pressures up to and including 250 psi cannot be set more than 10 per cent above or 10 per cent below that for which it is designed. Above 250 psi the valve cannot be set for more than 5 per cent above or below that for which it is designed. The reason for this is that the extra pressure might cause the coils on the safety valve to compress so much that there is no more space between the coils. The disk cannot lift any higher and the maximum pressure would be exceeded. Remember that the spring pressure is adjusted by turning the nut on the top of the spindle while the blowback is adjusted by turning the rings around the nozzle.



19. Safety valve springs are sometimes made of square stock to give greater clearance between the coils.

20. Every attached superheater must have one or more safety valves attached near the outlet of the superheater.

21. The discharge capacity of the superheater safety valve can be included in the overall relieving capacity of the boiler, but only for 25 per cent of the total relieving capacity.

22. You can tell the difference between a safety valve used for the boiler and one used on a superheater by the fact that the superheater safety valve will have the spring on the outside to protect it from the cutting action of the steam.

23. The superheater safety valve will pop before the boiler safety valve. The steam blowing through the superheater safety valve will keep the superheater tubes from burning up.

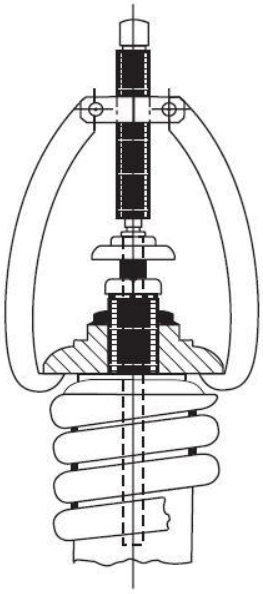
Safety Valve for Low Pressure Heating Boiler

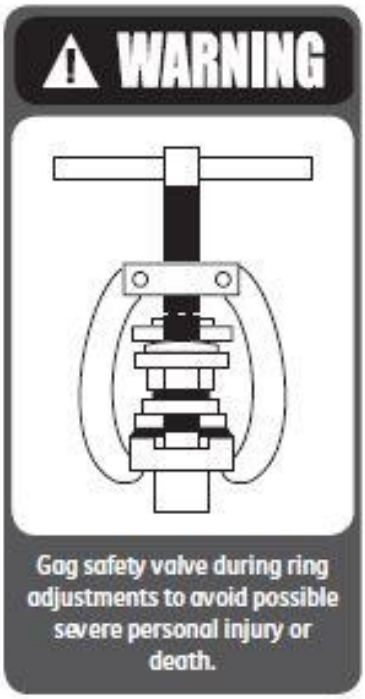
24. Safety valves for steam heating boilers shall not be less than 1 inch or greater than 4 and 1/2 inch standard pipe size.

25. Never reduce the inlet or outlet pipe size to a safety valve. If you reduce the pipe size down by 1/2, you decrease the area of the pipe by 4 times. The safety valve cannot relieve the pressure if the inlet or outlet is restricted.

26. If a safety valve leaks, try to reseat it by using the lifting lever at 75% of normal operating pressure. If the safety valve continues to leak, shut down the boiler at the first opportunity and have it repaired or replaced. Valve leakage may be caused by steam cutting the seat, a deformed valve body, a bent spindle, or improper adjustment of the blowdown.

27. Accurate steam gauges are needed to verify the correct popping pressure of the safety valve. A tee with a shutoff on the syphon is provided to allow the inspector to attach his gauge to verify that the gauge on the boiler is accurate.





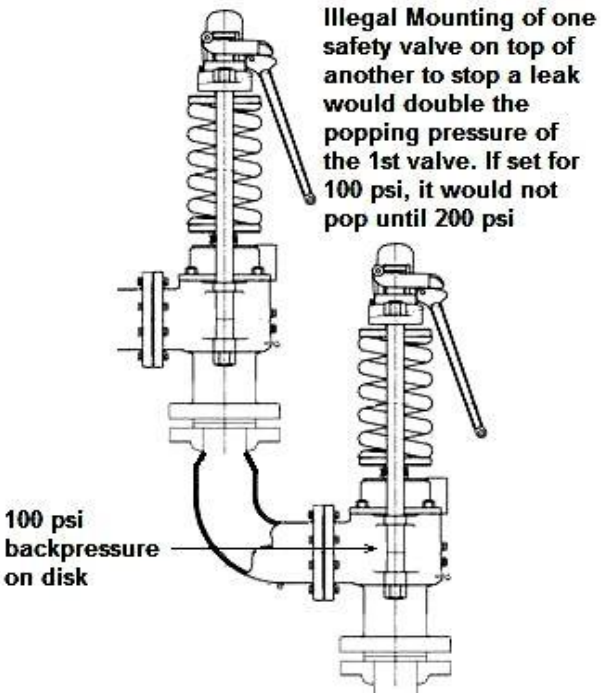
28. A safety valve gag is a device used to hold the disk of the valve on its seat during a hydrostatic test. The gag is only tightened finger tight so as not to bend the safety valve spindle. To prevent damage to the safety valve during a hydrostatic test, the safety valve can be removed and a blank flange installed over the opening. It is imperative to replace the safety valve when the test is completed.

During any hydrostatic test all safety valves on the unit must be gagged. This gagging procedure prevents the possibility of damage to the safety valve internals in the event that the test pressure exceeds the safety valve set pressure. When hydrostatic pressure will exceed the set pressure of the safety valve, it is recommended the valve be replaced with a blank flange during hydrostatic testing.

Probably the most common source at safety valve trouble is overgagging. During hydrostatic testing, and during safety valve setting, gags should be applied only hand tight. During setting, overgagging could cause damage to the seating surface and result in leakage. In applying gags remember that the valve spring will hold the valve closed against its set pressure. The additional gag load applied should be only enough to ensure that the valves do not lift at the expected over-pressure.

Gags should never be applied when the boiler is cold. The spindle of the safety valve expands considerably with the temperature increase as pressure is raised. If it is not free to expand with this temperature change, the spindle may be damaged. Boiler pressure should be increased to 80 percent of the pressure of the low set valve before applying the gags.

29. Never put a plug in the discharge of a safety valve and never place another safety valve on the end of the first in an attempt to stop a leak. Placing another safety valve on the outlet of the first will double the pressure at which the first valve will pop. You will have the spring pressure plus the steam pressure trapped between the two valves to overcome before the valve closest to the boiler will pop.


Illegal Mounting of one safety valve on top of another to stop a leak would double the popping pressure of the 1st valve. If set for 100 psi, it would not pop until 200 psi
100 psi backpressure on disk

30. Authorities vary on how often to test the safety valve. The ASME suggested rules say "periodically". The concern is that too frequent testing can erode the seat and cause leaking. Testing by raising the boiler to popping pressure should be done just before the boiler is brought down for inspection. Then if the valve leaks it can be repaired while the boiler is down. Once a month the lever should be raised to ensure that the valve is not sticking on its seat. A small rope and pulley is advisable to allow the Operator to lift the lever from the floor for convenience and safety. By Code the rope cannot place any pull on the lever while not being tested. A small spring is sometimes placed next to the valve attached to the rope to relieve the weight of the rope.

In the picture above and to the right, look how much steam is blowing around the valve at top. In the picture on the right, someone forgot to put a pipe plug in the drain. That much steam would scald you to death. Attach the rope and stay far away from the valve when testing by pulling the handle with the rope.

The safety valve is the most important valve on the boiler and the last line of defense before an explosion. Test it safely but test it. Bring the rope to the firing floor with no obstructions and there is no excuse not to test it.

Chapter 8 Questions

1. Why are safety valves called "pop" safety valves?
2. Why were weight loaded lever type safety valves outlawed?
3. What is the difference between a relief valve and a safety valve?
4. What is blowdown when referring to safety valves? How do you adjust it to increase the blowdown and in which direction?
5. What is the upper ring on the safety valve called?
6. What is the lower ring on the safety valved called? How and in which direction do you turn it to increase the blowdown?
7. What pressure should you have on the boiler before lifting the lever?
8. When all safety valves are blowing how much above the highest valve setting can the pressure increase?
9. You have three safety valves on a boiler with a MAWP of 1000 p.s.i. What are the minimum, maximum and other settings on the safety valves?
10. What data is on the safety valve tag?
11. Why can the safety valve have no shut off between it and the boiler?
12. Of what material can the seat of the safety valve be made?
13. Why are some safety valve springs made of square stock?
14. How is the popping pressure of the safety valve adjusted?
15. How can you tell the difference between the safety valve for a boiler and one for a superheater?
16. What is a safety valve gag?
17. Is it OK to run a hose from a leaky safety valve outside the boiler room?
18. Is it OK to put one safety valve on the outlet of another to stop a leak?

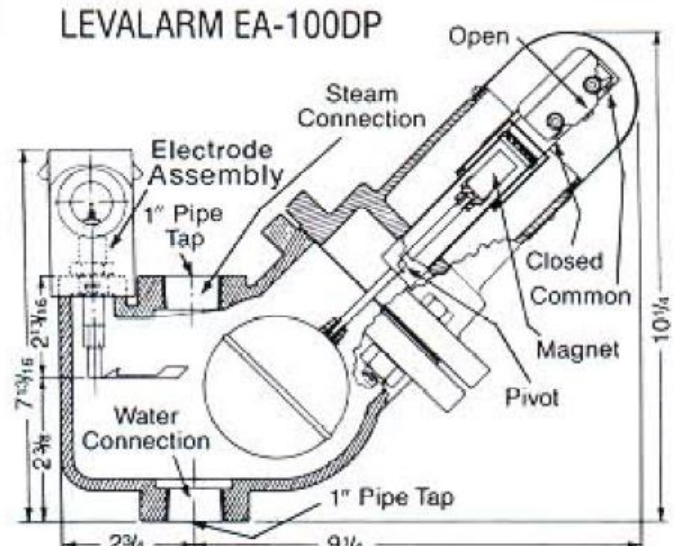
Chapter 9 Boiler Appliances & Auxiliaries

LOW WATER CUTOUT

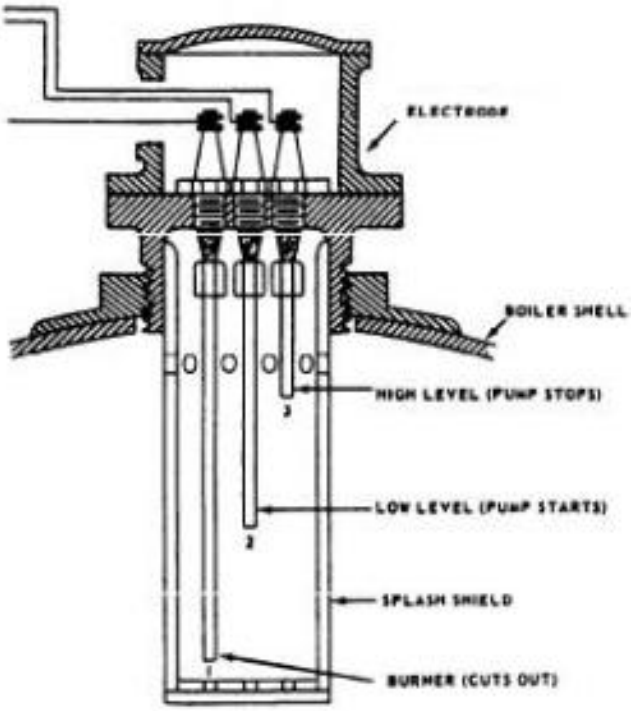
As stated above, the correct answer to the most important valve on the boiler is the safety valve; however, according to The National Board of Boiler and Pressure Vessel Inspectors Incident Reports of 1992-2003, the vast numbers of boiler failures were from:

1. Low Water Cut-out with 356 incidents
2. Poor Maintenance with 125 incidents

Safety valves were last in incidents with one.



Courtesy Clark-Reliance



Probe Type Low Water Cutout

Low Water Cut Out devices are normally very reliable and function well. But the following factors can lead to a breakdown.

Deposits — Condensate water and new make-up water entering a boiler can deposit minerals and solids.

Jumpers — Sometimes jumper wires are used as a temporary means to diagnose a problem or bypass a circuit for testing. If not removed, the LWCO cannot shut down the burner.

Age — Most manufacturers suggest periodic replacement of the mechanical and electrical components. If not, aging can cause electrical shorts, leaks and parts failure.

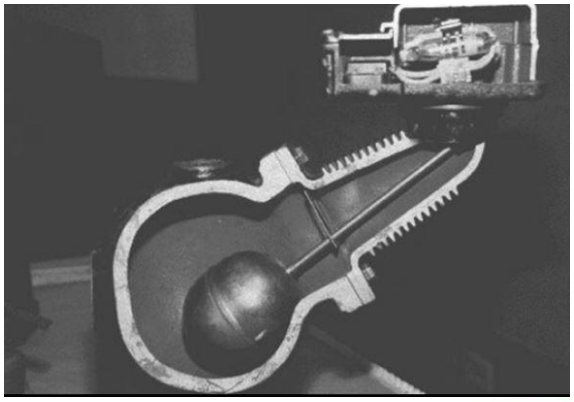
Maintenance — Proper boiler maintenance also requires purging the LWCO system. But be careful — improper flushing can also cause damage.

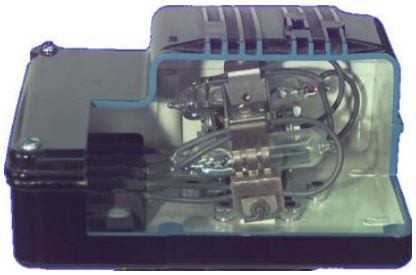
Loss of Water — Steam leaks, faulty steam traps and processes that require high percentage makeup water can all lead to boiler and LWCO problems from loss of water. Your entire system needs proper maintenance.

One of the main jobs of the Boiler Operator is to blow down the water column, sightglass, and low water cut out every shift. Boiler meltdowns and explosions happen when the low water cutout is faulty or the float bowl is plugged solid with mud and scale and the float cannot drop to shut the burner off. If the Low Water Cut Out has mercury switches that look dirty or cloudy inside, then the entire head assembly needs to be replaced.

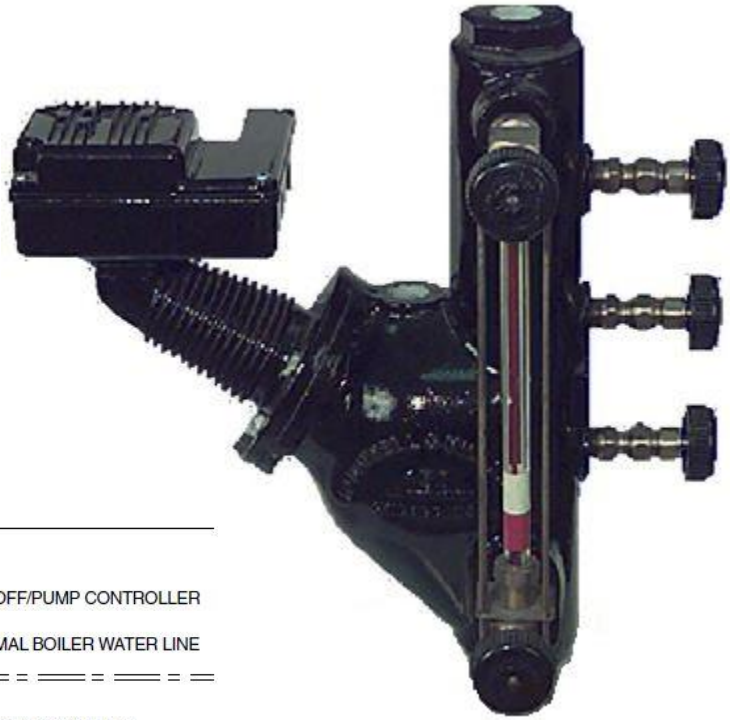
Clogged Boiler Low Water Cutoff (LWCO)

Courtesy Joe Moore & Company, Inc.

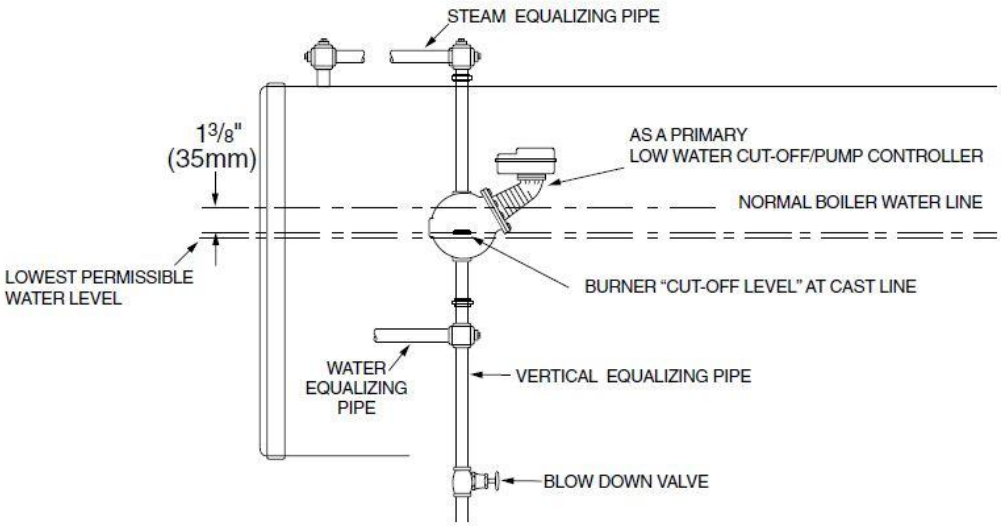




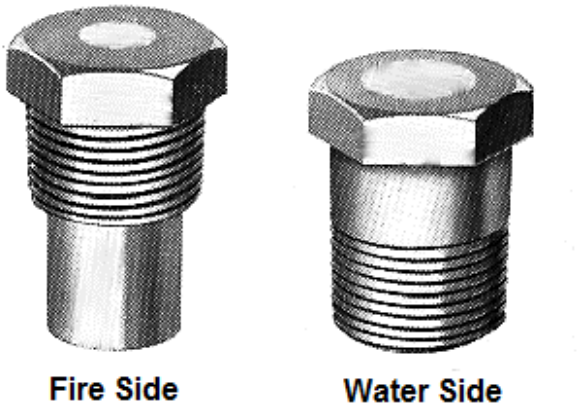
Mercury Switches



Courtesy McDonnell Miller


STEAM EQUALIZING PIPE
1 3/8" (35mm)
AS A PRIMARY LOW WATER CUT-OFF/PUMP CONTROLLER
NORMAL BOILER WATER LINE
LOWEST PERMISSIBLE WATER LEVEL
BURNER "CUT-OFF LEVEL" AT CAST LINE
WATER EQUALIZING PIPE
VERTICAL EQUALIZING PIPE
BLOW DOWN VALVE

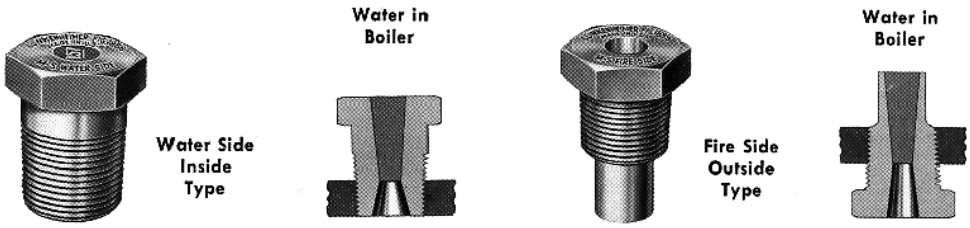
FUSIBLE PLUGS



A fusible plug is a threaded brass plug with a cone shaped hole through the center filled with a mixture of tin alloy that will melt at between 445 and 450 degrees Fahrenheit. The purpose of the fusible plug is to give a warning to the Operator in case of low water by melting the tin and blowing steam through the hole. The two types of fusible plugs are the fire-side and the water-side. The fire-side fusible plug is inserted from the outside or combustion chamber side of the boiler. The water-side fusible plug is inserted from the inside or water containing side of the boiler.

Important points to remember about fusible plugs are:

1. The composition of the material inside the fusible plug is
A. tin 99.3%
B. copper.....0.5% max
C. lead .....1.0% max



2. The plug will protrude at least 3/4 of an inch on the water side of the plate, tube, or flue. Many boilers have a requirement that at least 1 inch of the plug must protrude through the sheet on the water side.
3. If a fusible plug is inserted into a tube, the tube thickness cannot be less than .22 inch thick. This is almost 1/4 of an inch thick.

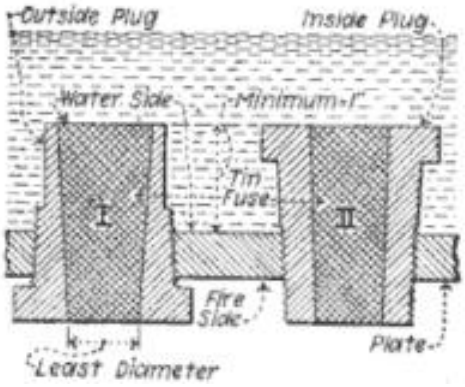
4. The large end of the cone has the tin and always faces the water. The pressure forces the tin tighter into the plug and the tin has to melt by the heat of the fire before the steam will blow through and sound the alarm.

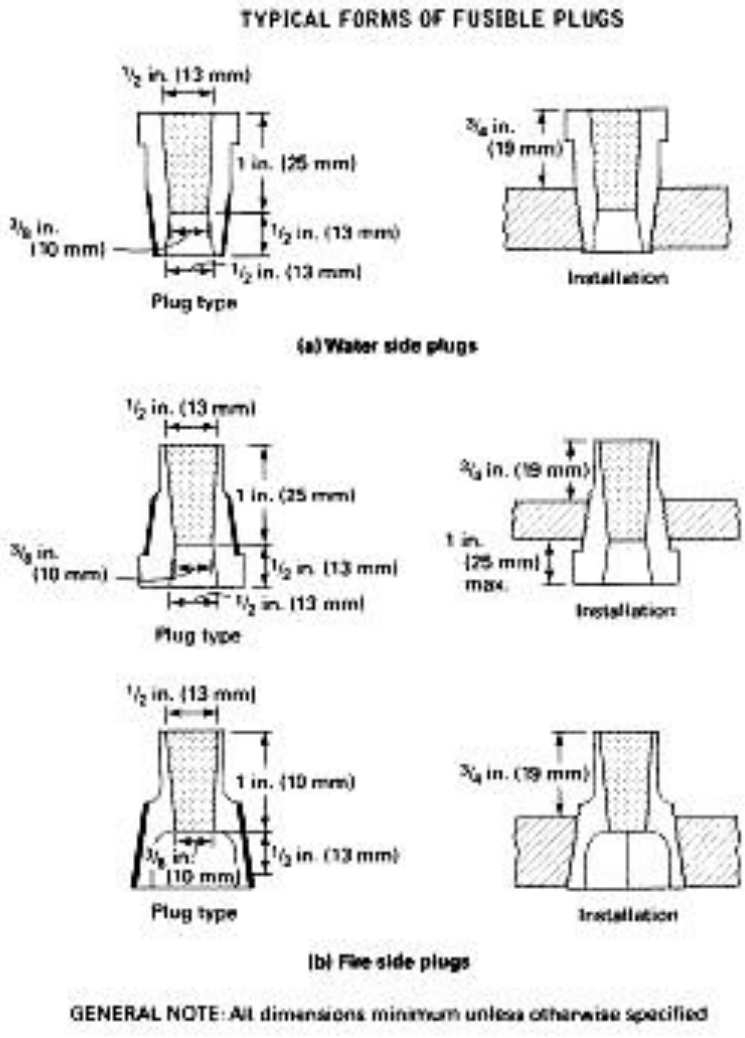
5. Above 250 psig a fusible plug is not used. At 250 psig the temperature of saturated steam is around 405 degrees F. This could lead to nuisance melting of the plug.

6. The fusible plug must be renewed at least once a year. You must use a new plug. You cannot pour new tin into an old casing.

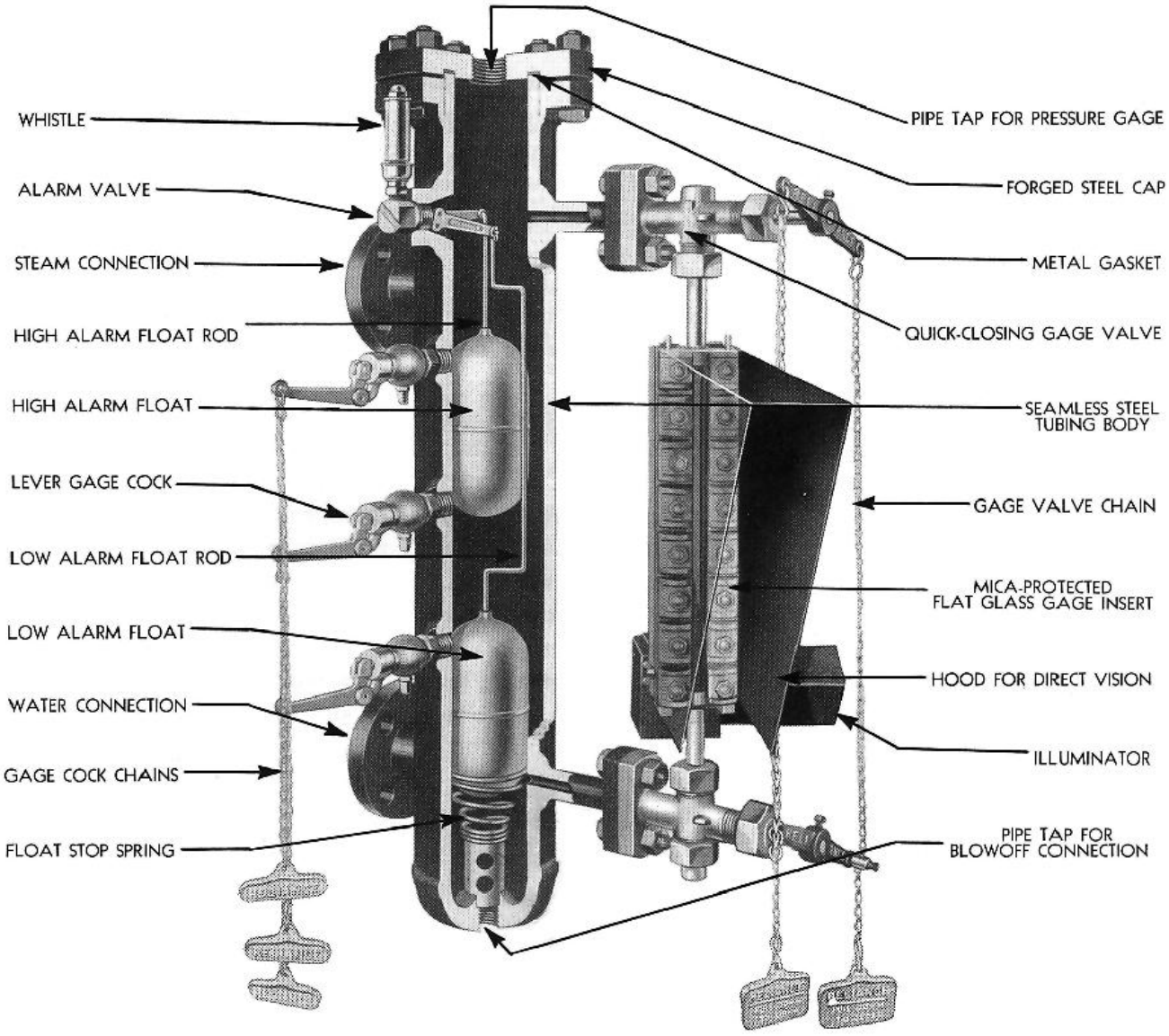
7. The low water cut-out has replaced the fusible plug in modern boilers.

8. The fusible plug will have "ASME STD" stamped in the large end of the tin.





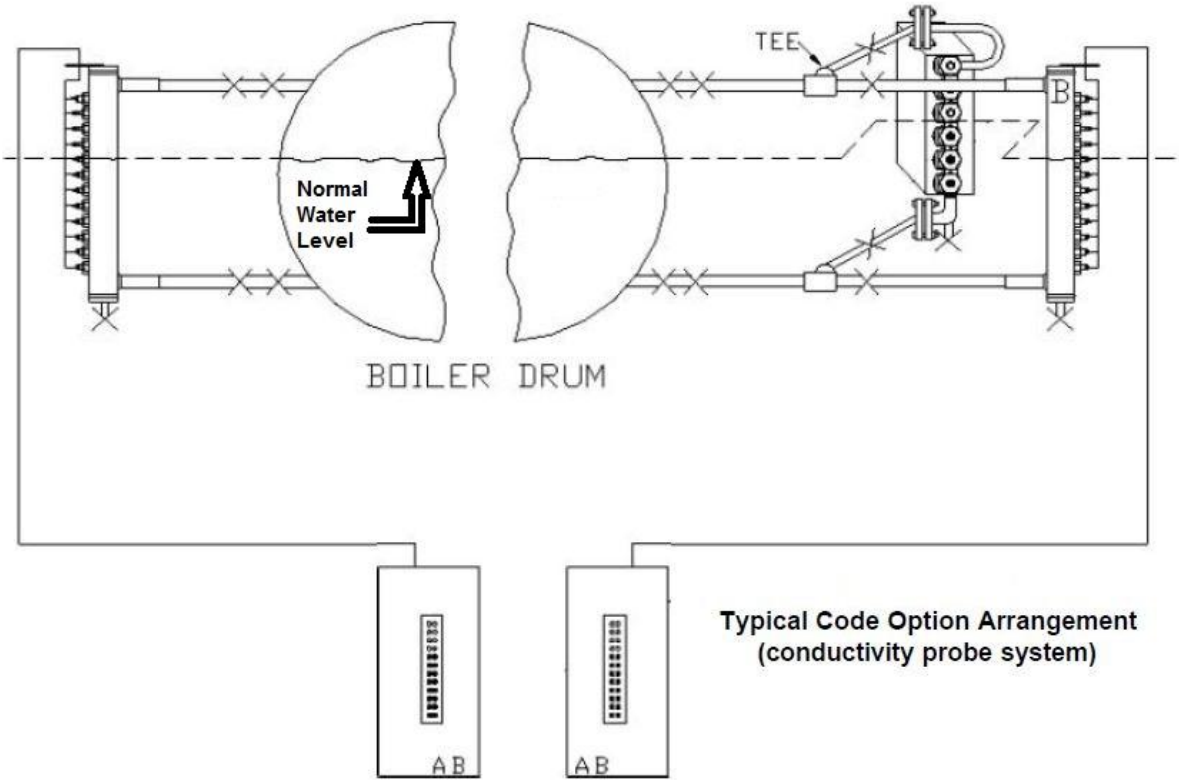
WATER COLUMNS



Courtesy Clark-Reliance

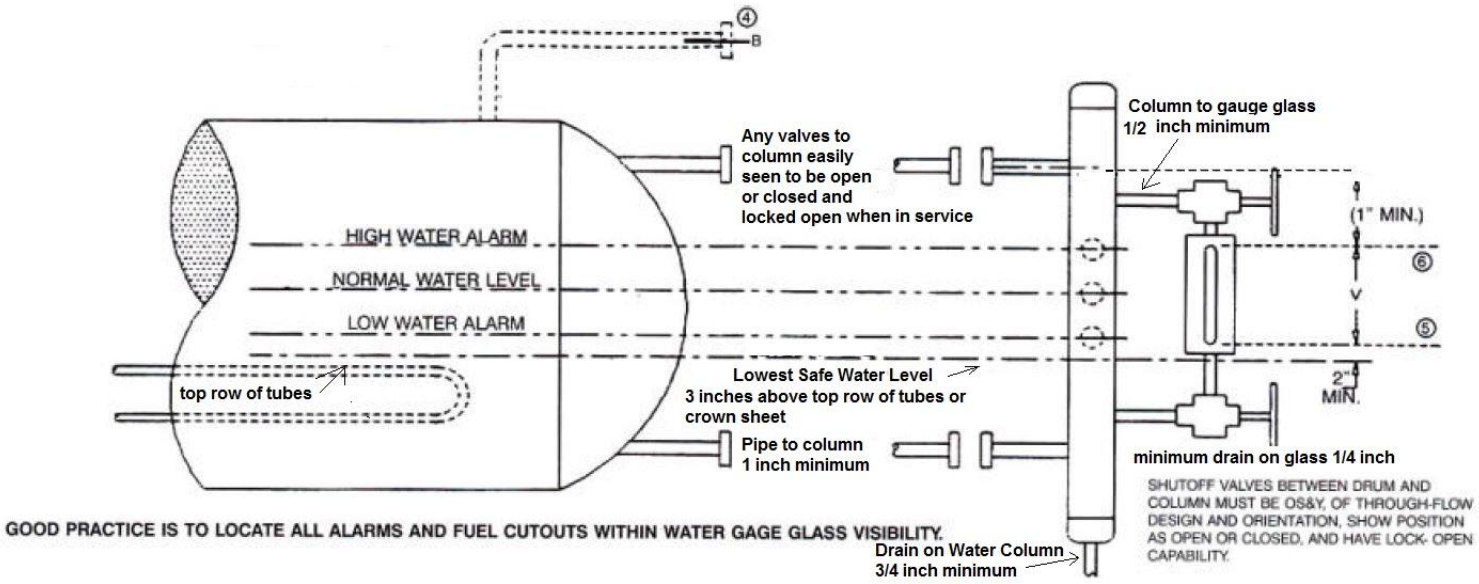
The water column and gauge glass is the "window" into the boiler. The purpose of the water column is to steady the water level in the gauge glass. The gauge glass will let you see the level of water in the boiler as well as if you are foaming or priming. The water column is a small cylindrical vessel that contains floats or weights hooked to a whistle that will blow in case of high or low water. It also has the connections to the boiler, the gauge glass, the try-cocks, steam gauge, and column drain. Making sure that the water column is correctly mounted and that the column piping and gauge glass are kept clear is a primary responsibility of the Boiler Operator.

Important points to remember about the water column are:



Typical Code Option Arrangement (conductivity probe system)

1. Each steam boiler shall have at least one water glass, the lowest visible part of which shall not be less than two inches above the lowest permissible water level. If the boiler is operated at over 400 psi, two gauge glasses are required. These gauge glasses may be connected to the same water column.


④
B
Any valves to column easily seen to be open or closed and locked open when in service
Column to gauge glass 1/2 inch minimum
HIGH WATER ALARM
NORMAL WATER LEVEL
LOW WATER ALARM
top row of tubes
Lowest Safe Water Level 3 inches above top row of tubes or crown sheet
Pipe to column 1 inch minimum
(1" MIN.)
⑥
V
⑤
2" MIN.
minimum drain on glass 1/4 inch
SHUTOFF VALVES BETWEEN DRUM AND COLUMN MUST BE OS&Y, OF THROUGH-FLOW DESIGN AND ORIENTATION, SHOW POSITION AS OPEN OR CLOSED, AND HAVE LOCK- OPEN CAPABILITY.
GOOD PRACTICE IS TO LOCATE ALL ALARMS AND FUEL CUTOUTS WITHIN WATER GAGE GLASS VISIBILITY.
Drain on Water Column 3/4 inch minimum

2. Horizontal fire tube type boilers (H.R.T., Locomotive, Scotch Marine, etc.) shall have the lowest water level in the gauge glass at least three inches above the highest part of the tubes, flues, or crown sheet.

3. The minimum size pipe connecting the water column to the boiler shall be no less than one inch

4. The minimum size pipe on the drain connection of the water column shall be no less than 3/4 of an inch.

5. The minimum size of the pipe connecting the water column to the gauge glass shall be no less than 1/2 inch.

6. The minimum size of the drain on the gauge glass is not less than 1/4 inch.

7. Cast iron can be used for water columns up to 250 psi.

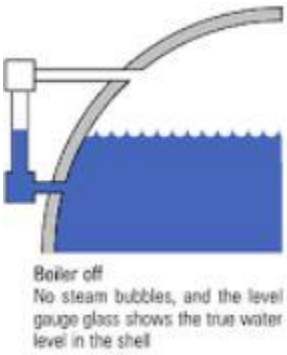
8. Ductile or malleable iron can be used for water columns up to 350 psi

9. For pressures over 350 psi, steel is used. The reason that steel is not used for the lower pressures is the corrosion resistance that cast iron offers.

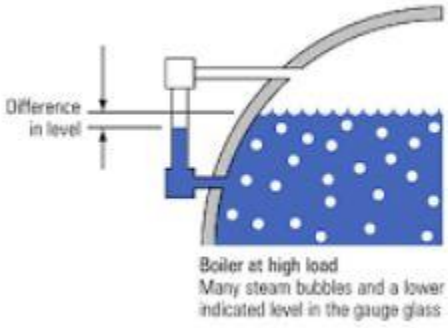
10. The steam connection on the column should pitch from the boiler to the column. The water connection of the column should pitch toward the boiler.

11. The water level in the boiler is a little higher than the water level in the water column because the water is a little cooler in the column.

12. The round gauge glass can be used for pressures up to 400 psi. It should have a protecting shield to protect the Boiler Operator from flying glass and steam should the glass break. This is an update to the ASME Code that should be used on all older installations. Above 400 psi the flat glass must be used.



Boiler off
No steam bubbles, and the level gauge glass shows the true water level in the shell



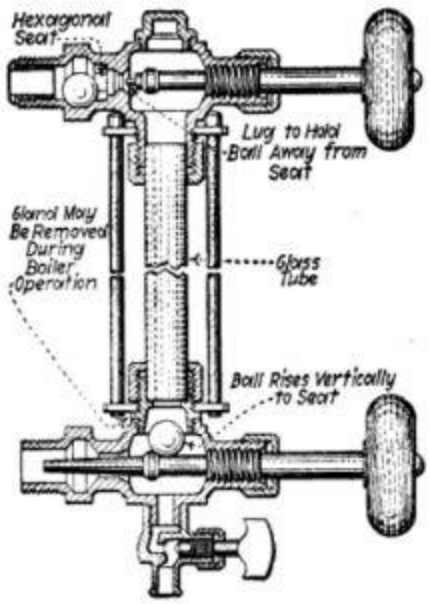
Boiler at high load
Many steam bubbles and a lower indicated level in the gauge glass

13. The pipe connections to the water column should be made up of crosses that allow the piping to be inspected and cleaned easily. The plugs in the two unused cross fittings are left open during inspection to allow the inspector to make sure that the passageways are not clogged shut.

This Valve would have to be chained open to be used between the boiler and the water column

14. If valves are on the piping connecting the water column to the boiler, they must be of the rising stem outside screw and yoke type, lever lifting type gate valves, or stopcocks with the plug held in place by a guard or gland, with markings to show whether they are open or closed. They must be locked in the open position.

15. There should be no connections on the water column except for damper regulators, feedwater regulators, drains, steam gauges or anything that does not use an appreciable amount of steam.


Hexagonal Seat
Lug to Hold Ball Away from Seat
Gland May Be Removed During Boiler Operation
Glass Tube
Ball Rises Vertically to Seat

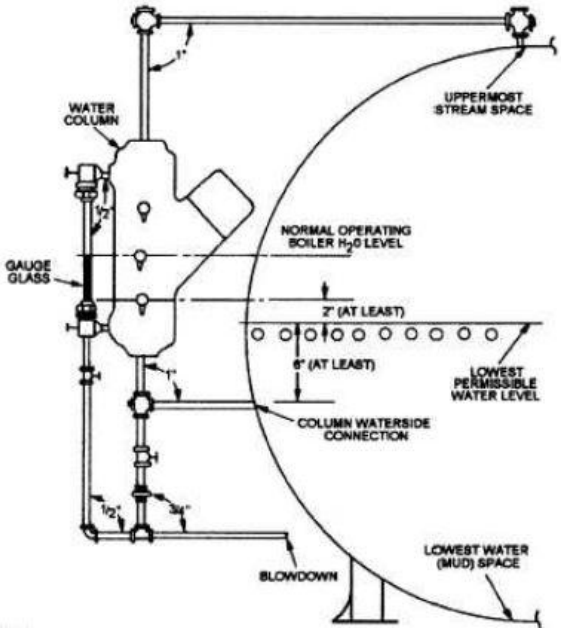
A gage glass which fulfills requirements of A.S.M.E. Code. (Pemberthy Injector Co.)

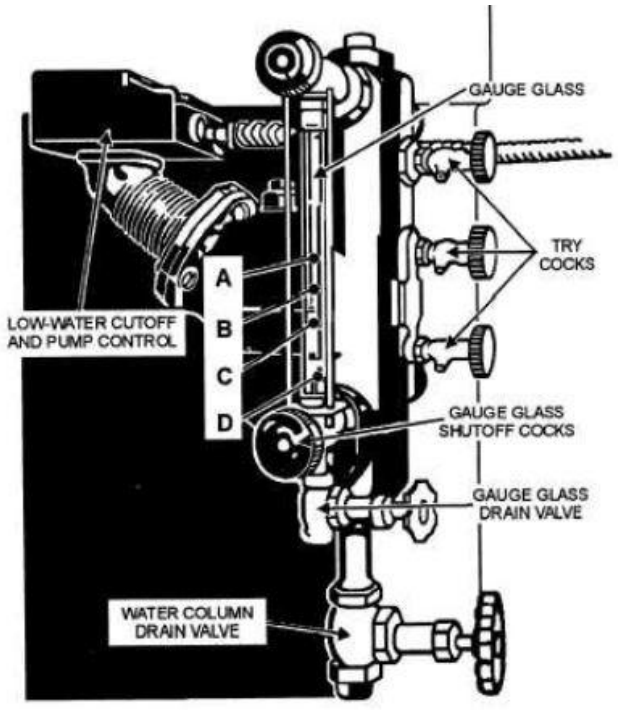
16. Automatic shutoff valves are sometimes used on the gauge glass connections to prevent large amounts of steam from blowing through the connections should a gauge glass break. This is done by having non-corrosive balls that lay in a special pocket next to the gauge glass. As long as the pressures in the water column and gauge glass are equalized, the balls sit in the pocket and a full opening is available to the gauge glass. Should the gauge glass break, the pressure in the boiler lifts the balls and forces them against the opening. The following special rules apply to the automatic shut-offs:

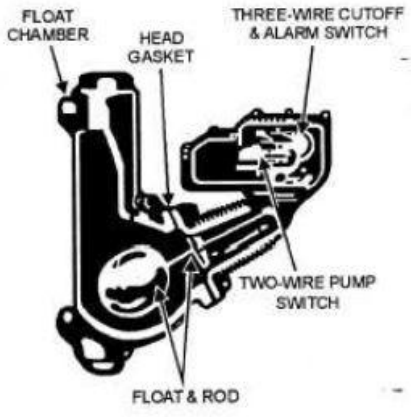
A. The balls cannot be smaller than 1/2 inch.
B. The upper ball cannot have a circular seat; it must be square or hexagonal so that the steam passage cannot be completely closed by this valve.
C. The lower ball must rise vertically to its seat.
D. You must have means to remove and inspect the lower ball while the boiler is under pressure.

17. The water column connection of most water tube boilers is at the top and bottom of the main steam drum.

18. The way to tell if the water column and gauge glass is connected correctly to the boiler is to shut down the boiler following all safety procedures. Shut off the burner and open all electrical disconnects. Close fuel, steam and water valves to the boiler, and let it cool to room temperature. Vent the boiler and lower the water level in the boiler until it is just about to go out of sight in the gauge glass. Open the manhole by loosening the nuts and then break the gasket seal free by hitting the manhole cover with the wooden handle end of a large hammer. Then remove the nuts and manhole cover. Measure the level from the top row of tubes or crown sheet to the top of the water. The water level should be 3 inches for most fire tube boilers (HRT's, Scotch Marine, Locomotive, etc.) and not less than two inches in any case.







A. HIGH LEVEL OF WATER: FEED PUMP TURNS OFF AT THIS POINT. FILL PRESSURE VESSEL INITIALLY TO THIS HEIGHT.

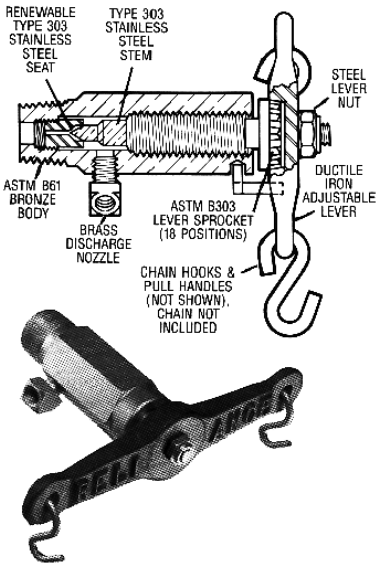
B. PUMP TURNS ON WHEN LEVEL REACHES B. DISTANCE A-B IS APPROXIMATELY 3/4 INCH

C. LOW WATER CUTOFF POINT. BUNER WILL SHUT OFF IF WATER LEVEL LOWERS TO THIS POINT.

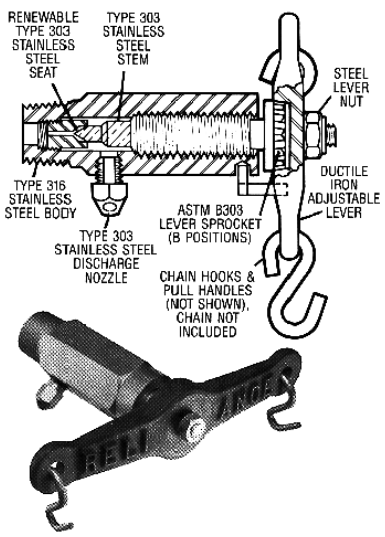
D. FIRST VISUAL POINT OF GAUGE GLASS.

Courtesy McDonnell Miller

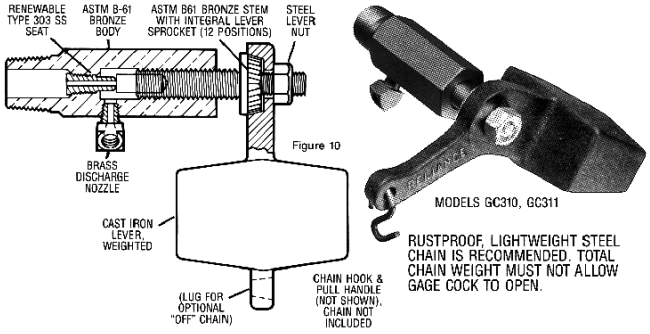
BRONZE BODY, CHAIN OPERATED GAGE COCKS: PRESSURES TO 450 PSI

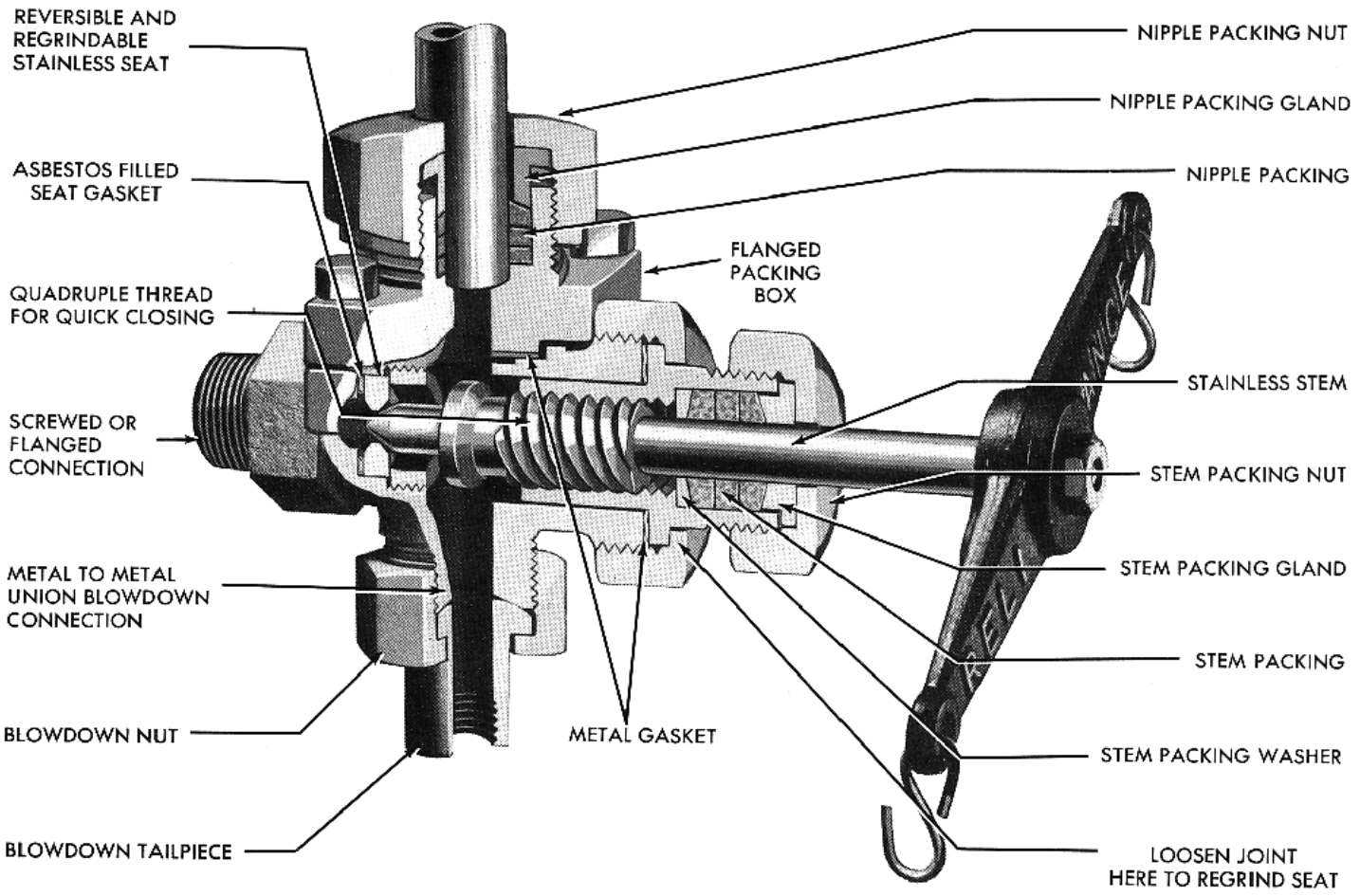

RENEWABLE TYPE 303 STAINLESS STEEL SEAT
TYPE 303 STAINLESS STEEL STEM
STEEL LEVER NUT
DUCTILE IRON ADJUSTABLE LEVER
ASTM B61 BRONZE BODY
BRASS DISCHARGE NOZZLE
ASTM B303 LEVER SPROCKET (18 POSITIONS)
CHAIN HOOKS & PULL HANDLES (NOT SHOWN), CHAIN NOT INCLUDED
RELIANCE

STAINLESS STEEL, CHAIN OPERATED GAGE COCKS: PRESSURES TO 1500 PSI

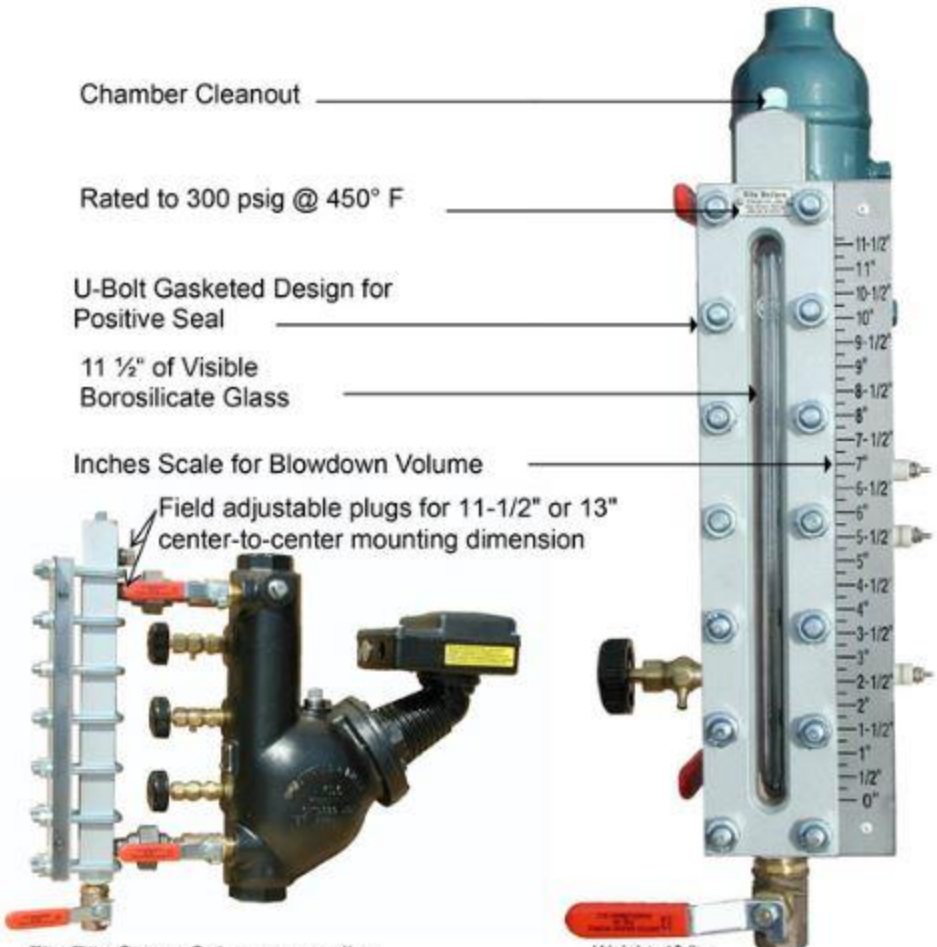

RENEWABLE TYPE 303 STAINLESS STEEL SEAT
TYPE 303 STAINLESS STEEL STEM
STEEL LEVER NUT
DUCTILE IRON ADJUSTABLE LEVER
TYPE 316 STAINLESS STEEL BODY
TYPE 303 STAINLESS STEEL DISCHARGE NOZZLE
ASTM B303 LEVER SPROCKET (8 POSITIONS)
CHAIN HOOKS & PULL HANDLES (NOT SHOWN), CHAIN NOT INCLUDED
RELIANCE

BRONZE BODY, CHAIN & WEIGHT OPERATED GAGE COCKS FOR MAXIMUM PRESSURES TO 250 PSI


RENEWABLE TYPE 303 SS SEAT
ASTM B-61 BRONZE BODY
ASTM B61 BRONZE STEM WITH INTEGRAL LEVER SPROCKET (12 POSITIONS)
STEEL LEVER NUT
Figure 10
BRASS DISCHARGE NOZZLE
CAST IRON LEVER, WEIGHTED
(LUG FOR OPTIONAL "OFF" CHAIN)
CHAIN HOOK & PULL HANDLE (NOT SHOWN), CHAIN NOT INCLUDED
MODELS GC310, GC311
RUSTPROOF, LIGHTWEIGHT STEEL CHAIN IS RECOMMENDED. TOTAL CHAIN WEIGHT MUST NOT ALLOW GAGE COCK TO OPEN.
RELIANCE

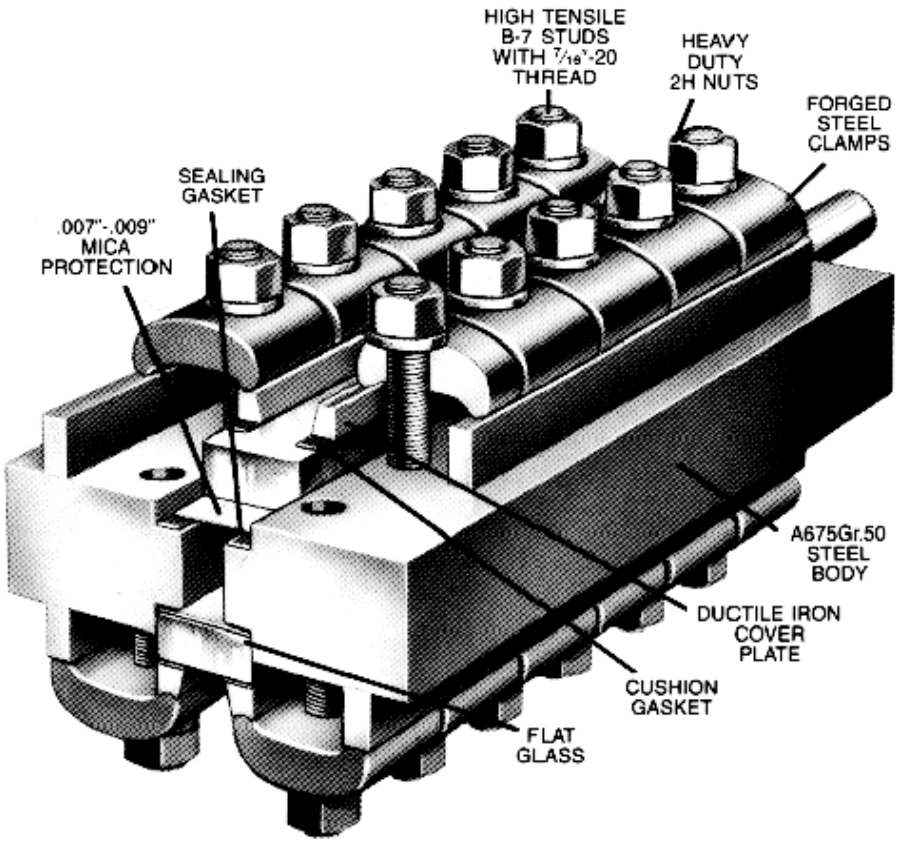


Various types of trycocks and gauge glass shutoff valves Courtesy Clark-Reliance



Fits Rite Steam Columns as well as **McDonnell & Miller 193, 194, & 157 Series**

Weight: 18 lbs.
Height: 16 ¾"
Width: 4"
Projection from steam column: 9"



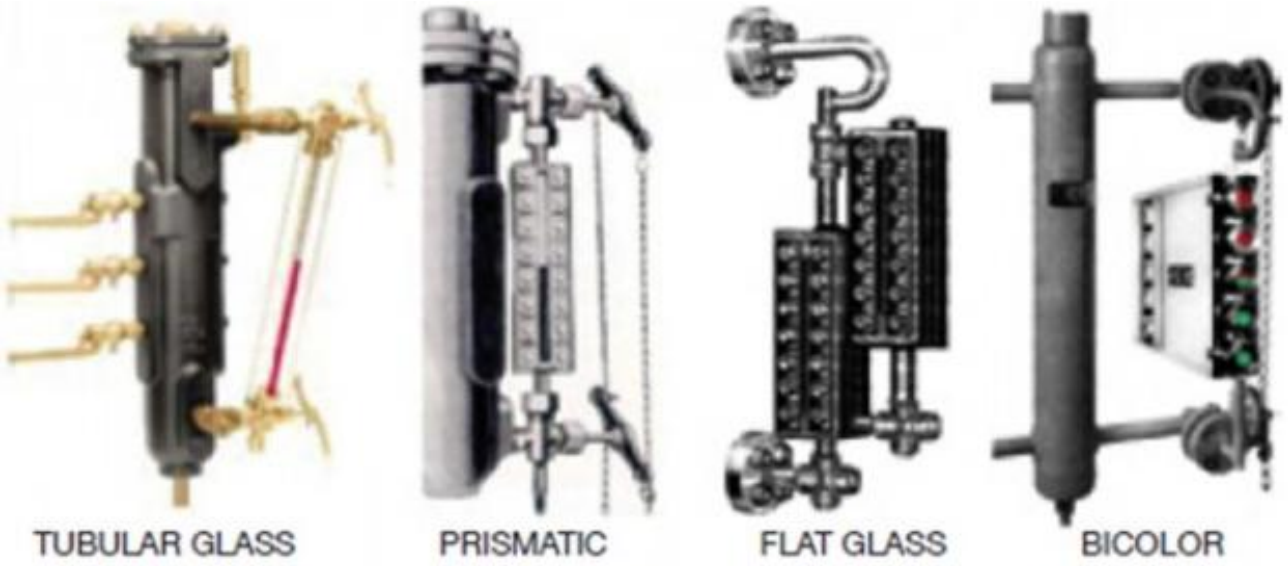
Tubular type
water / liquid level gauge

Reflection type
water level gauge

Transparent type
water level gauge

Bicolor type
water level gauge

Bicolor type
water level gauge
(multi-port type)



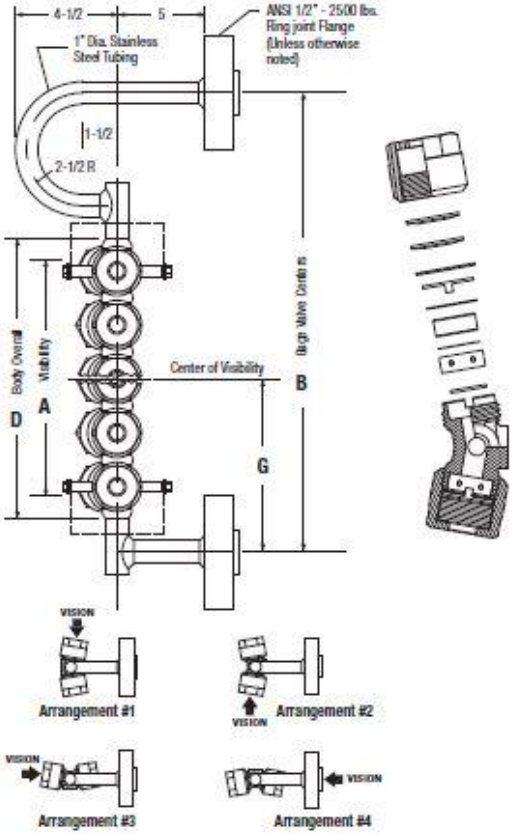
TUBULAR GLASS

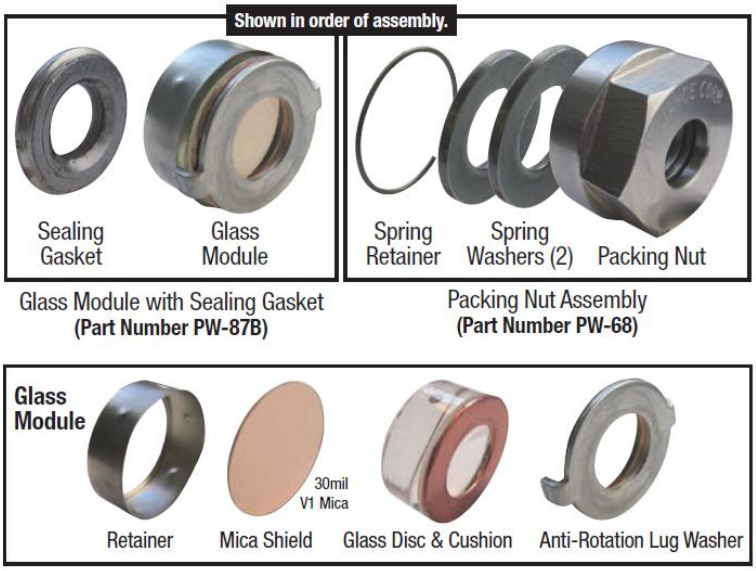
PRISMATIC

FLAT GLASS

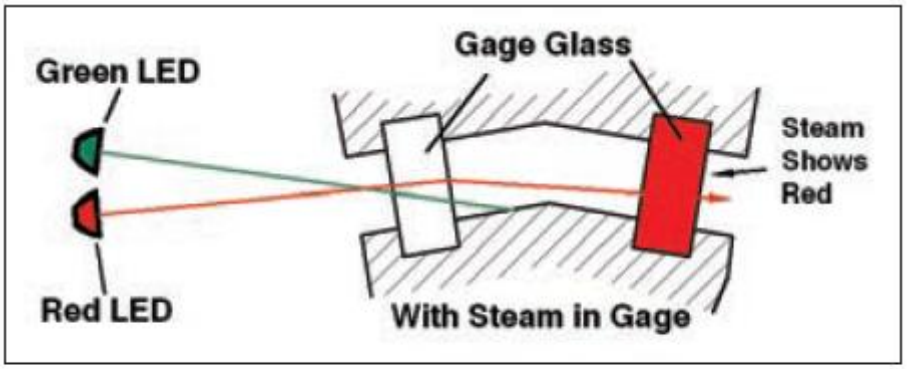
BICOLOR

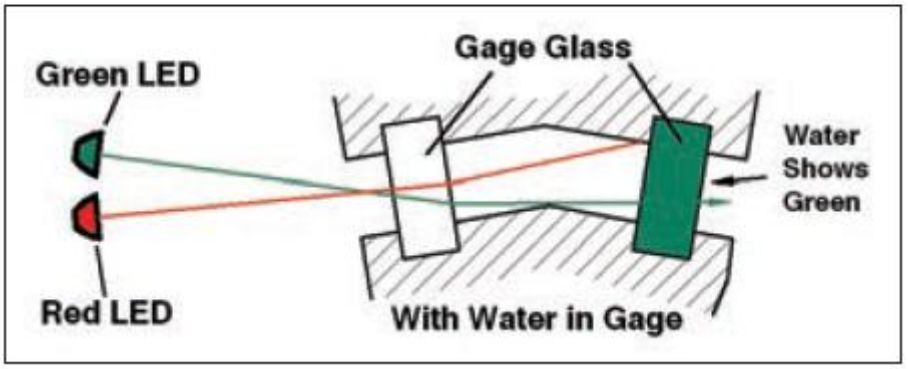
1. There are four types of direct-reading gage glasses (l to r): Tubular (up to 250 psig), prismatic (up to 350 psig), flat glass (up to 2000 psig), and bicolor (up to 3000 psig)


4-1/2
5
ANSI 1/2" - 2500 lbs. Ring joint Flange (Unless otherwise noted)
1" Dia. Stainless Steel Tubing
1-1/2
2-1/2 R
Body Overall
Visibility
A
D
Center of Visibility
Bugle Valve Centers
B
G
VISION
Arrangement #1
Arrangement #2
Arrangement #3
Arrangement #4


Shown in order of assembly.
Sealing Gasket
Glass Module
Glass Module with Sealing Gasket
(Part Number PW-87B)
Spring Retainer
Spring Washers (2)
Packing Nut
Packing Nut Assembly
(Part Number PW-68)
Glass Module
30mil V1 Mica
Retainer
Mica Shield
Glass Disc & Cushion
Anti-Rotation Lug Washer

SIMPLIPORT
by CLARK-RELIANCE

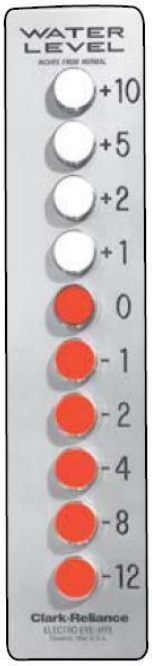

Green LED
Gage Glass
Steam Shows Red
Red LED
With Steam in Gage


Green LED
Gage Glass
Water Shows Green
Red LED
With Water in Gage

MINIATURE RED

ALL INDICATORS ARE SHOWN APPROXIMATELY 1/3 ACTUAL SIZE
SEE TABLE D BELOW FOR SPECIFIC DIMENSIONS

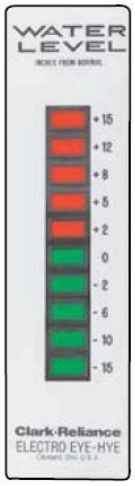
STANDARD RED



STI-SERIES

MTI SERIES
- Miniature LED

MINIATURE BI-COLOR



MTI-BI-COLOR SERIES
- Miniature LED
- Green for water, red for steam

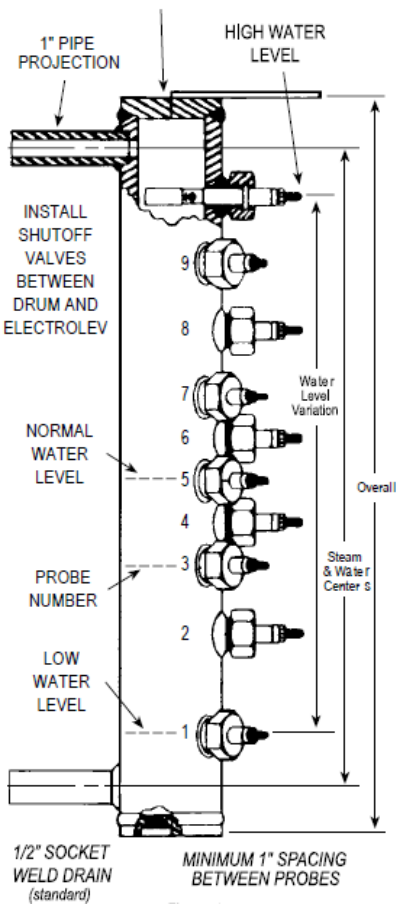
SUBMINIATURE BI-COLOR

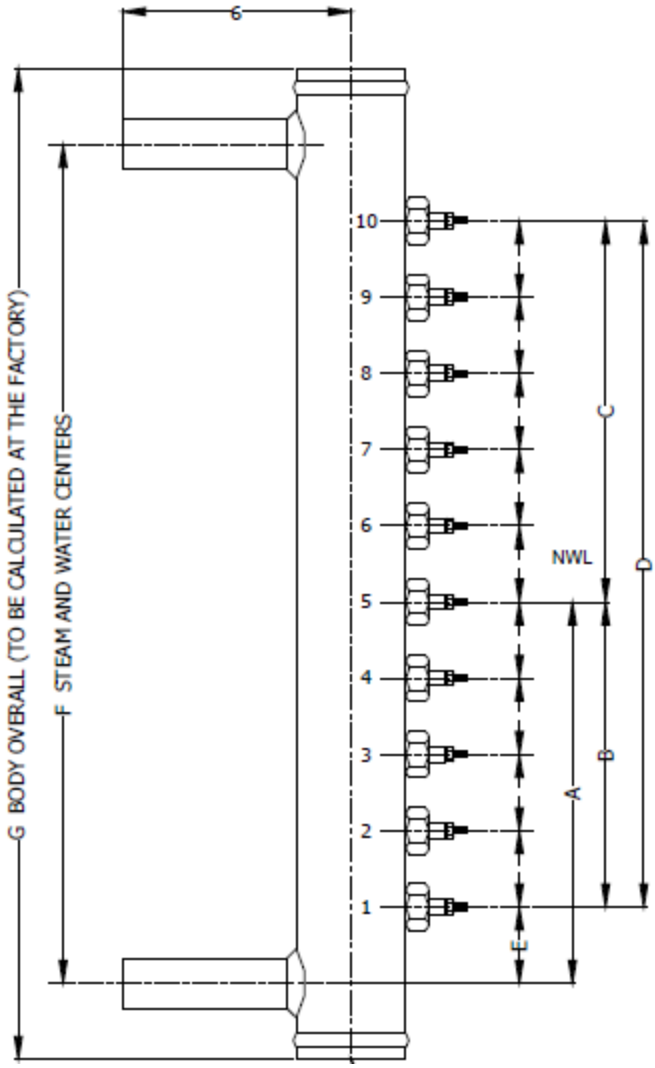
SMI-BI-COLOR SERIES
- Subminiature LED
- Green for water, red for steam

SMI - 10BR
12BR
20BR

TCB TRI-COLOR SERIES
These models require the PC-27 (4-20mA) and fault detector control unit options, in order to operate on the 4 wire circuit.

STANDARD CONNECTIONS
HOUSING REMOVED

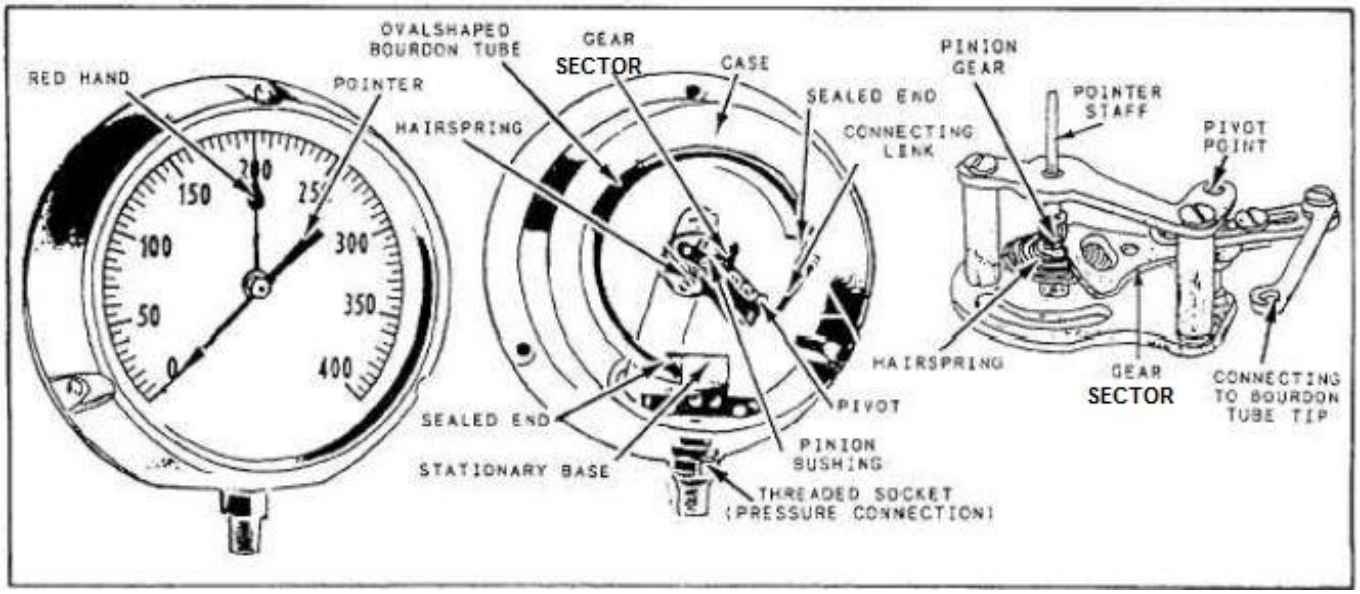




REMOTE SENSING WATER COLUMNS

The Code allows two remote level sensors to take the place of one of the two required gauge glasses for boilers operating over 900 psi. They are required when the Boiler Operator cannot readily see the water level from his normal working area. In larger plants, the boilers can be ten stories tall or taller with the steam and water drum near the top floor. The central control room is normally on the firing floor where the burners are located which is usually on the third or fourth floor. Either a system of mirrors that allow an Operator to see the gauge glass or the remote sensors are needed. The remote sensors illustrated show the water column with probes at different levels in the water column. As the water rises in the boiler and in the column, the water completes an electrical circuit at each probe and illuminates a light at the remote level indicator that represents the water level. They are either set up with one color (usually red) indicating the water level by being lit and the steam level unlit, or else they use a two color system where the water level is represented by a green light and the steam space is represented by a red light. They can also have the water level green and the steam red.

STEAM GAUGES



A steam gauge measures the pressure on the boiler. The major component of the steam gauge is the bourdon tube, an oval curved tube that will try to straighten itself out into a straight cylinder when pressure is applied. The party favors that you blow into, unrolling from a tight curl into a straight tube, illustrate the principle of the bourdon tube. Attached to the end of the tube is a link, the other end of which is connected to the sector. A sector is a section of a large gear, hence the name. The sector gear meshes with the pinion gear. The pinion gear's center is connected to the pointer and as the pinion is turned by the sector, the pointer shows the pressure on the dial of the case. A small spring serves to keep the linkages and pivot points tight.

Important points to remember about the steam gauge are:

1. The steam gauge measures pressure above atmospheric pressure.

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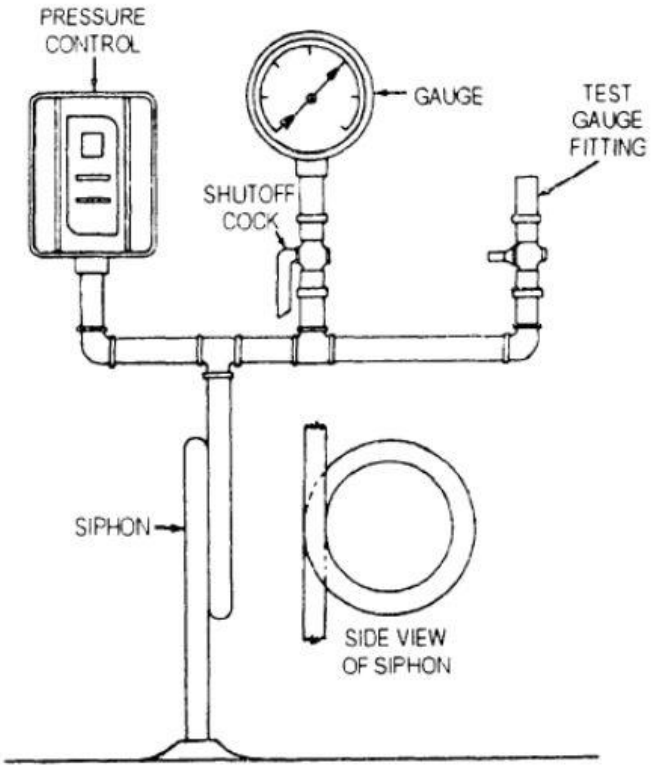
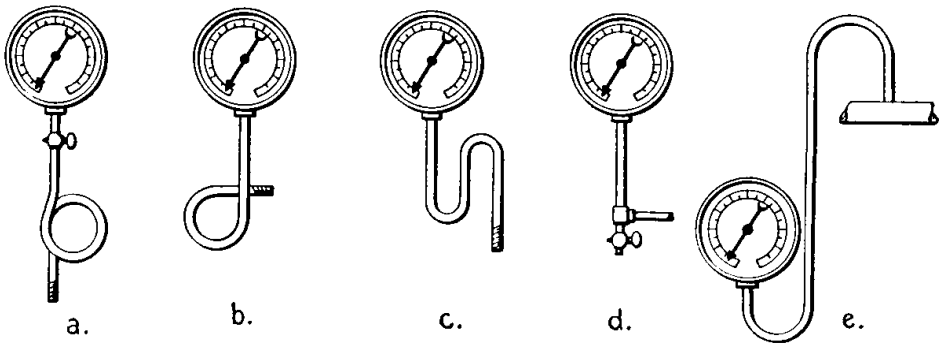


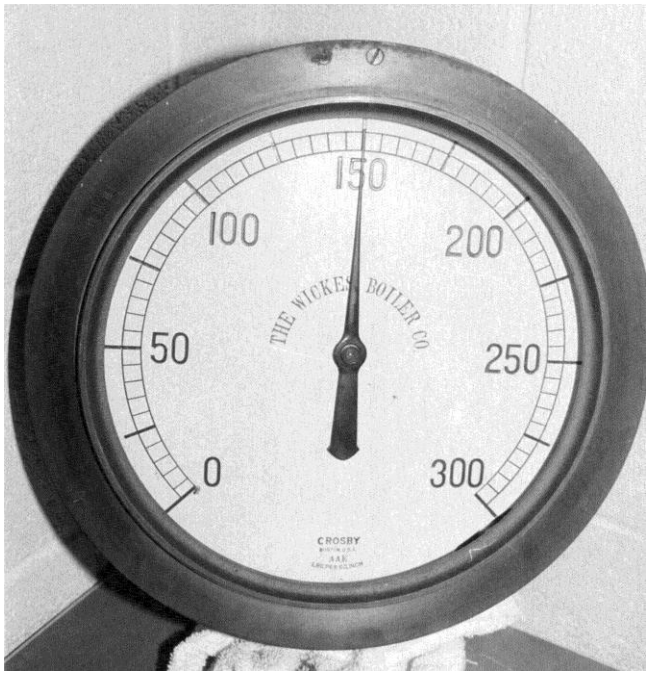
2. The steam gauge is connected correctly to the steam space of the boiler or at the steam space of the water column. The siphon must be as shown. If the side view were connected to a mercury switch, the loop would bend and give erroneous results.

3. Each boiler must have a 1/4 inch minimum pipe connection with a valved shutoff to allow the Inspector to attach a test gauge so he can check the accuracy of the steam gauge on the boiler while the boiler is in service. Normally this valve is on an elbow attached to a tee on the steam gauge pipe. This allows the inspector to see both gauges easily.

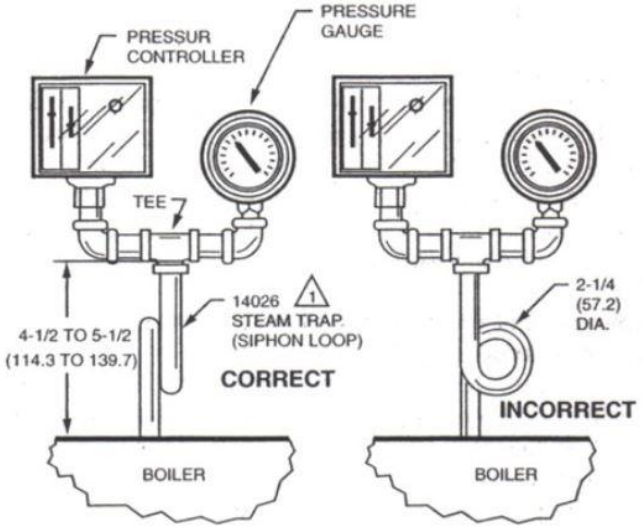


4. The steam gauge has a syphon, gooseneck, or pigtail between the gauge and the boiler. These are used to collect condensate so that the hot steam cannot damage the gauge. The minimum inside diameter is 1/4 inch.

5. The gauge cannot be shut off from the boiler except by a stopcock or ball valve with a tee or lever handle that is in line with the pipe when the gauge is open. The stopcock must be placed at the gauge inlet. Another shutoff valve next to the boiler is allowed but it must be locked open. The Code used to require that the pipe to the steam gauge be over 10 feet in length before a shutoff at the boiler was allowed, but that requirement has been dropped.



6. The steam gauge must read at least 1 and 1/2 times the setting of the safety valve. Preferred practice is to have the gauge read 2 times the setting of the safety valve and has the normal operating pressure at the 12 O'clock position. The pointer is then straight up when the boiler is operating normally and it is easy for the Operator to check. The normal operating pressure for the boiler on the right is 150 psi.



BOTTOM BLOWDOWN VALVES

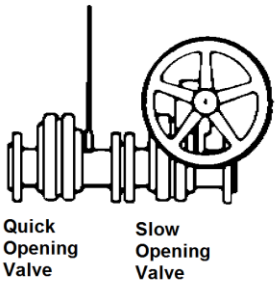
Blowdown valves or blowoff cocks are used to:

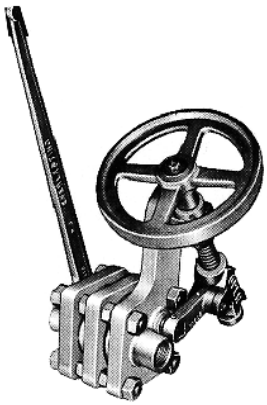
1. rid the boiler of sludge and sediment

2. lower the water level in case of high water

3. drain the boiler for cleaning, repair, and inspection

4. lower the concentration of chemicals in the boiler





There are two general types of blowdown valves, the quick-opening and the slow-opening. The slow-opening blowdown valve is defined as one that takes at least five 360 degree turns to go from fully open to fully closed. The water treatment tests will determine how often to blow down the boiler, but it is usually not less than once every 24 hours.

Important points to remember about blowdown valves are:

1. The minimum pipe size for a blowdown valve is 1 inch and the maximum pipe size for a blowdown valve is 2 and 1/2 inches. The exception to this rule is boilers under 100 square feet of heating surface, whose minimum pipe size for a blowdown valve is 3/4 inch.

2. A bottom blowoff cock shall have the plug held in place by a guard or gland. The guard or gland keeps the pressure from blowing the plug out of the valve body. The end of the plug will be marked to show the correct flow.

3. Globe or gate valves are not to be used as blowdown valves. The globe valve will clog with mud or scale, and the gate valve will get scale trapped beneath the gate and prevent closing.

4. When the pressure on a stationary boiler exceeds 125 psi, two blowdown valves must be used, one after the other. They can either be two slow-opening valves or a quick-opening and a slow-opening valve. When a quick-opening valve and a slow-opening valve are used together, the quick-opening valve must be closest to the boiler.

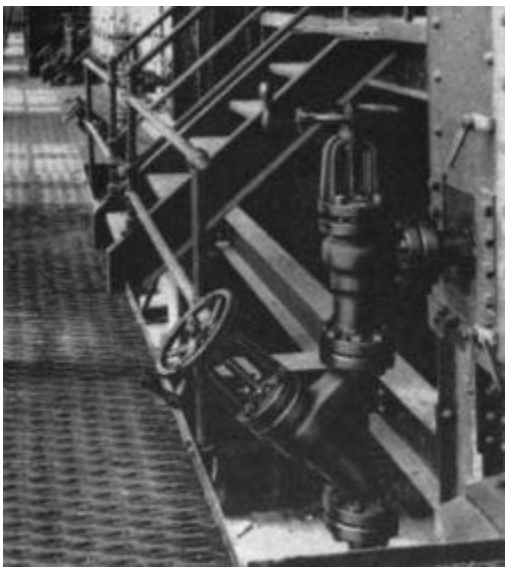
5. Two valves in one casing can be used as long as the failure of one valve does not affect the operation of the other.

6. All integral economizers, waterwalls, or waterscreens have the same requirements as boilers.

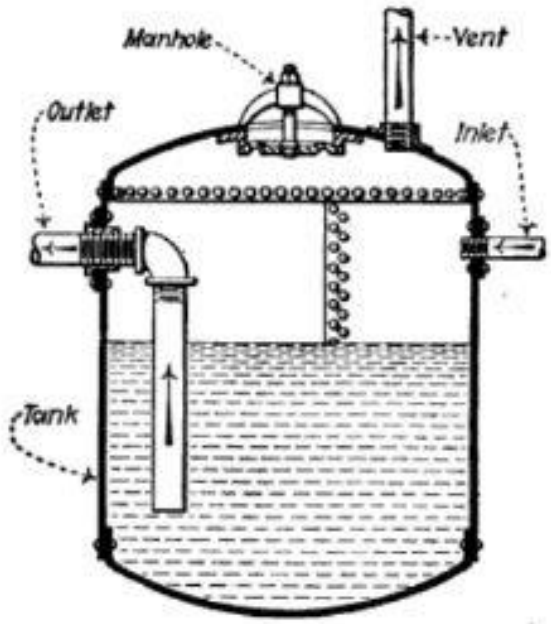
7. Steel blowdown piping must be used for pressures over 100 psi.

8. Steel valve bodies must be used for pressures over 250 psi.

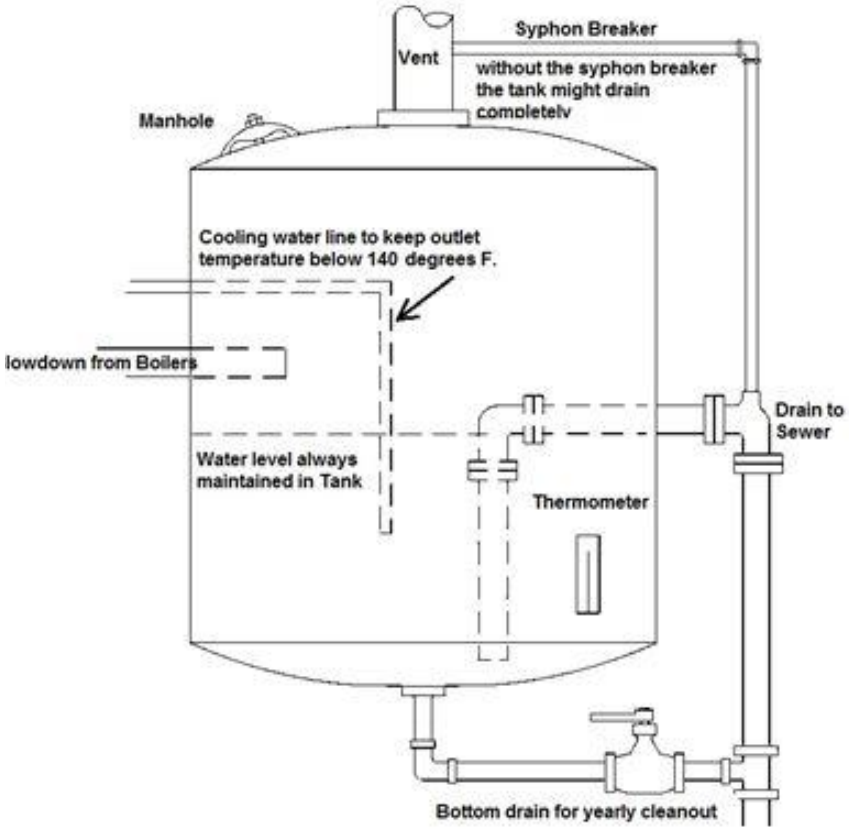
9. Be sure and open the blowdown valve fully when blowing down. Any partial opening would tend to cut the valve.



BLOWDOWN TANKS

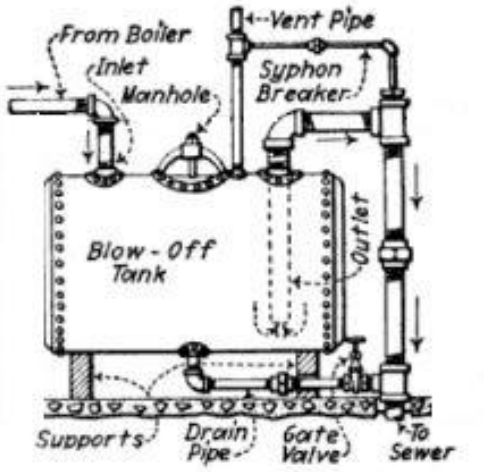


A blow-off tank.

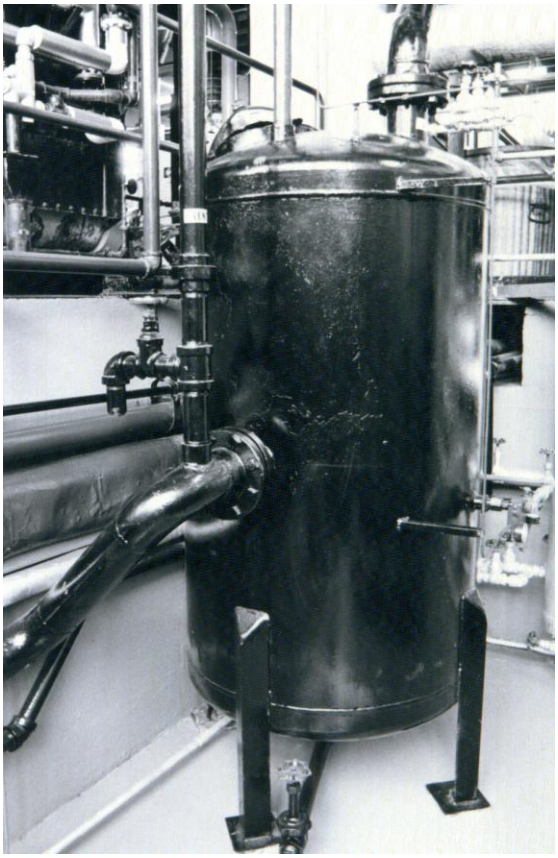

Syphon Breaker
Vent
without the syphon breaker the tank might drain completely
Manhole
Cooling water line to keep outlet temperature below 140 degrees F.
lowdown from Boilers
Drain to Sewer
Water level always maintained in Tank
Thermometer
Bottom drain for yearly cleanout

Because the blowdown water from the boiler can damage the sewer, a blowdown tank is required to cool the water before the water is discharged to the sewer. It also prevents the steam and hot water from backing up through the sewer to come out at other drains. It also prevents sewer gas from backing up into the boiler while it is open for inspection. The blowdown tank is kept almost full of water at all times and the incoming hot water from the boiler must mix with the cool water in the blowdown tank before the water is allowed to discharge to the sewer. A large vent to the atmosphere prevents the buildup of pressure in the tank. A syphon breaker prevents the discharge pipe from acting as a syphon and draining the tank by admitting air to the discharge line to break the vacuum produced by the water flowing through the discharge pipe.

Important points to remember about blowdown tanks are:



Typical blow-off tank with piping pertaining thereto.



1. Cast iron construction is prohibited when the boiler is over 100 psi.

2. All blowdown tanks must have sufficient volume to handle one gauge of water, that being defined as the volume of water between the upper try-cocks within the visible range of the water glass on the boiler.

3. The water must be cooled to 140 degrees Fahrenheit before it is allowed to discharge to the sewer. This temperature requirement may vary with local plumbing codes.

4. The vent from the blowdown tank must be at least 5 times the area of the blowdown outlet from the boiler.

5. The inlet lines to the blowdown tank are the same size as the outlet from the boiler. The inlet to the blowdown tank is above the water level in the tank.

6. Blowdown tanks cannot be buried; they must be visible for inspection.

7. Blowdown tanks have manholes and handholes for access for cleaning. Minimum handhole size is 3" X 4" elliptical.

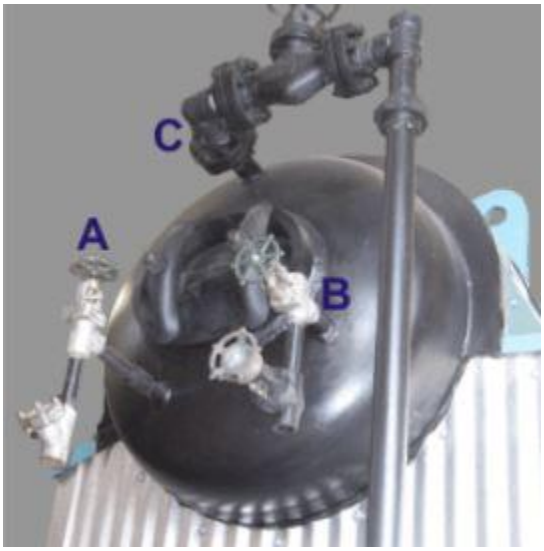
8. The discharge outlet cannot be less than three inches from the bottom of the blowdown tank.

9. Blowdown tanks have a bottom drain to drain the water out for cleaning.

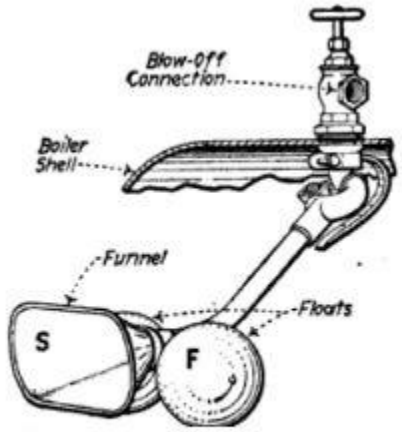
10. The minimum plate thickness of the blowdown tank is 3/8".

11. The Blowdown tank is located below the boiler.

CONTINUOUS AND SURFACE BLOWDOWN LINES



Chemical feed line is at "A". Continuous blowdown line is at "B". Sootblower steam line is at "C".

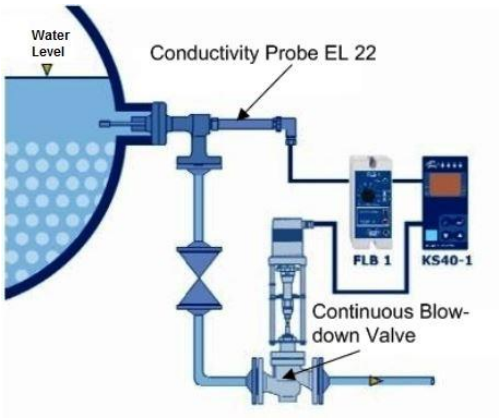


Skimmer which floats.

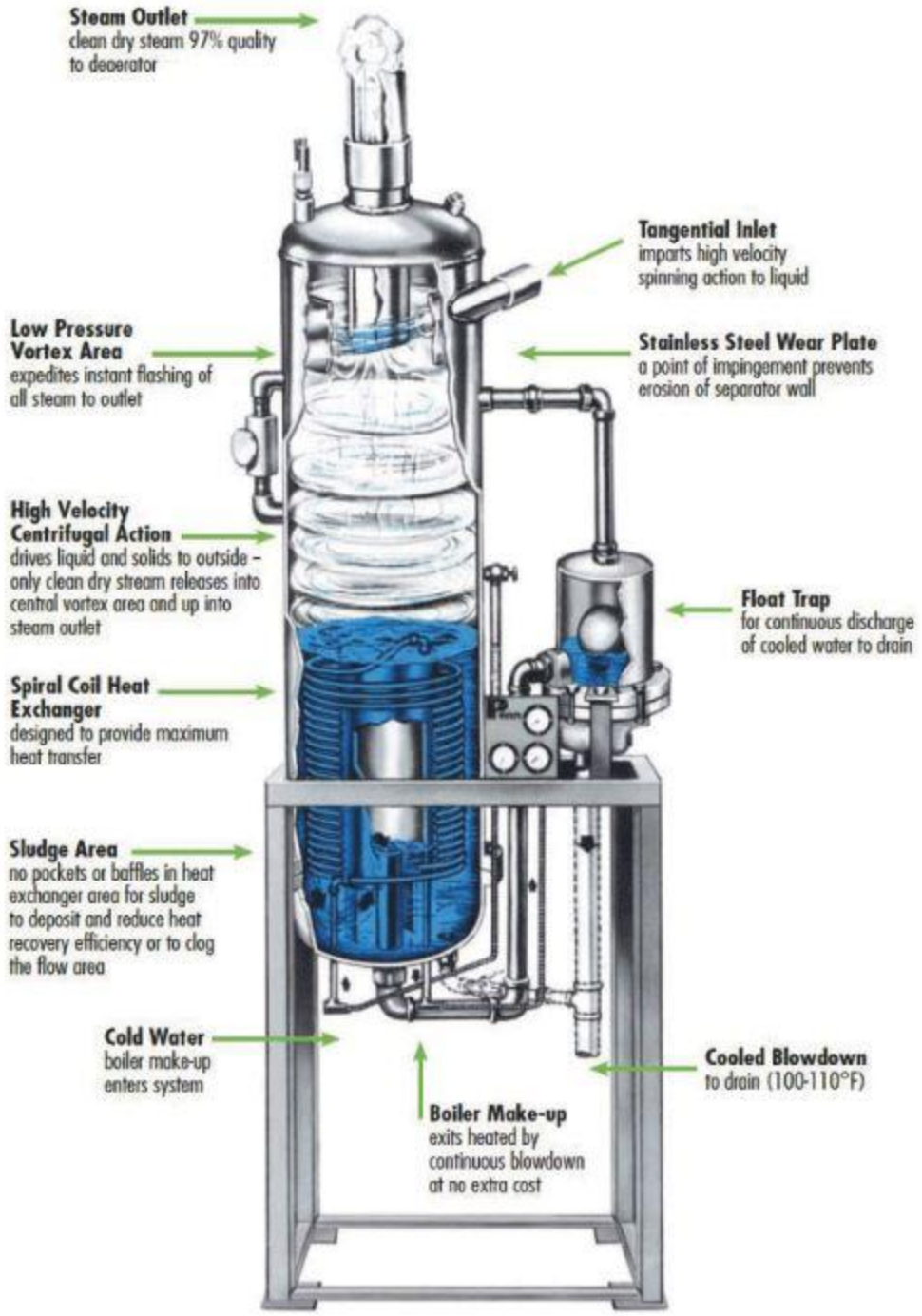
Sediment and the scale forming chemicals in the boiler are either lighter or heavier than water. The heavier particles are gotten rid of through the bottom blowdown valves. The lighter particles are controlled by the continuous or surface blowdown valves. The terms surface and continuous blowdown are used to mean the same thing in most literature, but the continuous blowdown is normally considered to be a pipe that enters the drum at a little below the normal water level, and is solidly connected inside the drum. The surface blowdown has a swivel joint connected to a float on the inside of the boiler that rides on the surface of the water and "skims" the impurities from the water. The other end of the blowdown line is connected to a control valve that is left open to control the amount of solids in the boiler. The boiler water chemical test will determine how wide to open the valve. The discharge from the continuous or surface blowdown valve is usually run through some type of heat exchanger, called a flash economizer, before going to the blowdown tank in order to save energy. The surface or continuous blowdown line can be no larger than 2 and 1/2 inches. If the concentration of solids becomes too high, foaming and priming can occur, and excessive sludge can restrict circulation and heat transfer causing rupturing and blistering of boiler tubes or shell. Since the concentration is greatest at the point of highest steam release, the best location for the continuous blowdown is just below the water level in the boiler.

At this point of highest concentration (about 4” to 6” below the water level), boiler water is continually drained off to reduce the concentrated boiler water. Fresh make-up water with a much lesser concentration is, at the same time taken, into the boiler. While this is the best method of controlling Total Dissolved Solids (TDS) in the boiler, valuable heat can be lost.

The Flash Economizer saves Money. Continuous blowdown of 1 gallon per minute on a 150 psig boiler wastes 169,000 BTUs/Hr. This blowdown water, too hot to dump to streams or public sewage, must be cooled to at least 140°F in most locations. Tempering this water with added cold water or just taking the water and dumping it to a hot well or blowdown tank becomes costly because you're losing both flash steam and hot water which can be recycled into the boiler. This water can be cooled by sending it through a Flash Economizer, which takes the heat out of the continuous blowdown and recycles it back into the make-up water. The drain temperature is reduced to 100-110°F.



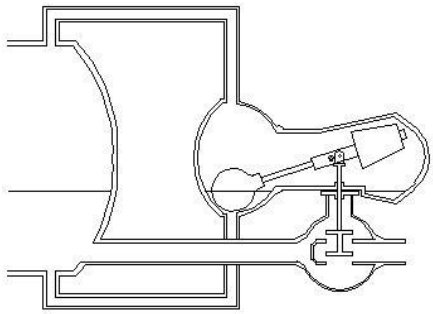
With a Flash Economizer most of the heat is recycled back into the boiler. A Flash Economizer saves more BTUs than a conventional heat exchanger. When a percentage of the continuous blowdown flashes into steam in the upper portion of the Flash Economizer, 100% recovery of the BTUs in flash stream is possible. Also, with the high cost of treating make-up water, you reclaim a percentage of the blowdown water in flash stream and put it back into the system.

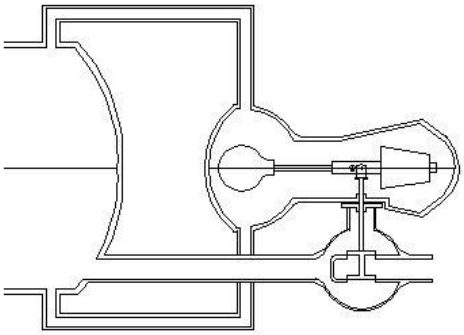

Steam Outlet
clean dry steam 97% quality to deaerator
Tangential Inlet
imparts high velocity spinning action to liquid
Low Pressure Vortex Area
expedites instant flashing of all steam to outlet
Stainless Steel Wear Plate
a point of impingement prevents erosion of separator wall
High Velocity Centrifugal Action
drives liquid and solids to outside – only clean dry stream releases into central vortex area and up into steam outlet
Float Trap
for continuous discharge of cooled water to drain
Spiral Coil Heat Exchanger
designed to provide maximum heat transfer
Sludge Area
no pockets or baffles in heat exchanger area for sludge to deposit and reduce heat recovery efficiency or to clog the flow area
Cold Water
boiler make-up enters system
Cooled Blowdown
to drain (100-110°F)
Boiler Make-up
exits heated by continuous blowdown at no extra cost

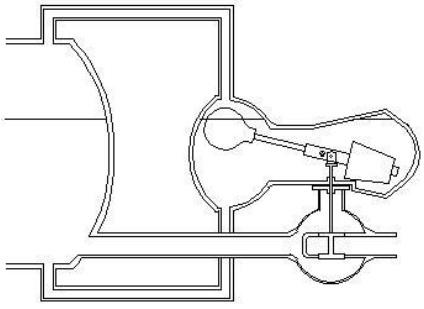
Courtesy Pennseparator

FEEDWATER REGULATORS

The purpose of the feedwater regulator is to control the flow of water to the boiler in response to the steam demand fluctuations of the load. If 100,000 pounds of steam per hour are leaving the boiler, then 100,000 pounds of water must enter the boiler to maintain the same water level. There are four basic types of feedwater regulators, the simple float type, the thermo-hydraulic (Bailey), the thermo-mechanical (Copes), and the powered type.



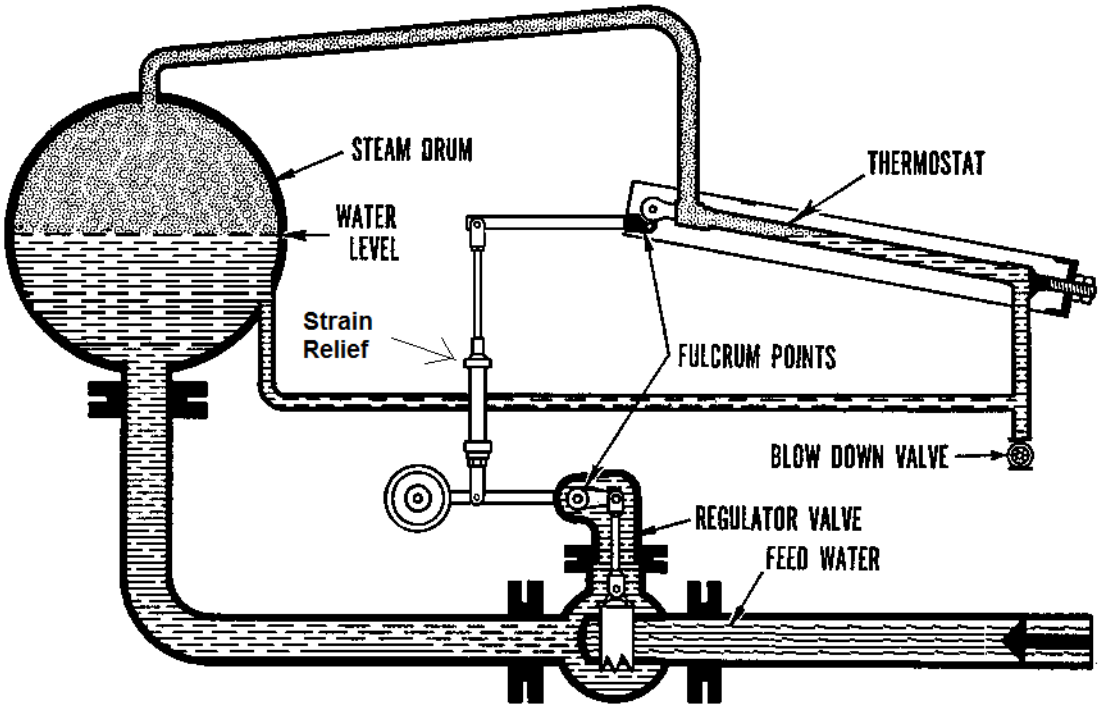




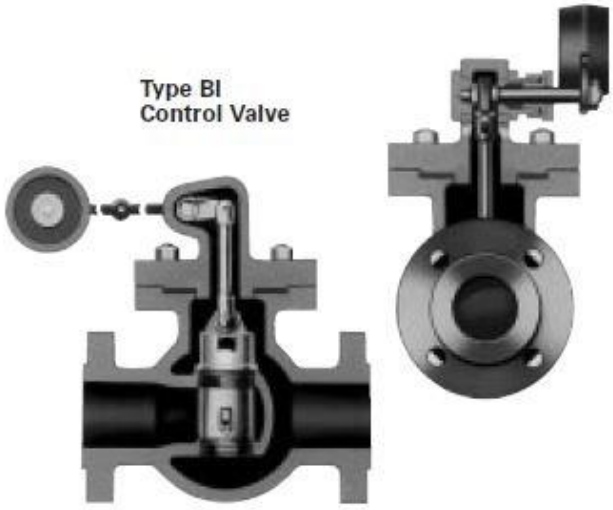
FLOAT TYPE

The simple float type as illustrated has a counter-balanced float hooked to a stem that operates the balanced valve in the feedwater line. Any drop in the water level causes the float to drop, raising the valve and allowing water to enter the boiler. If the water level in the boiler becomes too high the float moves the valve toward the closed position.

COPES FEEDWATER REGULATOR

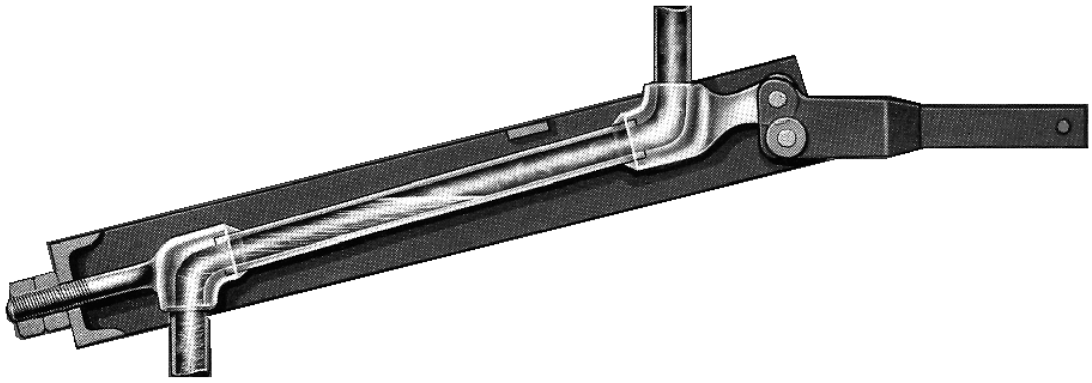


The thermo-mechanical or Copes type feedwater regulator uses a tube set on a slight angle with the normal water level of the boiler. As the water level in the boiler drops, the water level drops in the Copes tube. The steam connection allows steam to take the place of the water in the thermostatic tube and heats the tube. This heating causes the tube to expand and move a lever attached at a pivot point to the frame surrounding the tube. As the lever moves down the end of the lever is attached by a 3/8" length of pipe connected to a strain relief device which is then connected to the feedwater valve. The valve is the balanced type with a counterweight and therefore moves freely with minimum force. Because the linkage to the valve is pivoted between the length of pipe moving down, as the pipe moves down, the feedwater valve moves up and allows water to enter the boiler. As the water level rises in the boiler, the water level rises in the Copes tube and contracts the tube as it cools. This causes the feedwater valve to close.



Important points to remember about the Copes feedwater regulator are:

1. The Copes tube is 68 inches or 80 inches long depending on model. It is set at an angle so that the bottom of the tube is 8" lower than the top.



2. If the boiler pressure is 250 psi or less, the centerline of the tube is set one inch below the normal water level. This means that the upper end of the tube will be three inches above the normal water level and the lower end of the tube will be five inches below the normal water level. If the boiler runs at a pressure between 250 psi and 400 psi then the tube centerline is 2 inches below the normal water level and if the pressure is above 600 psi then the tube centerline is set 3 inches below the normal water level.

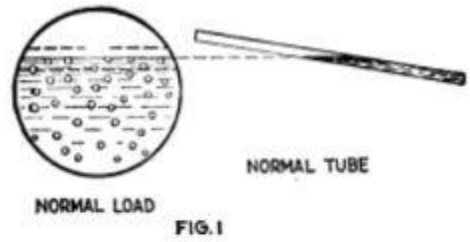


FIG. 1

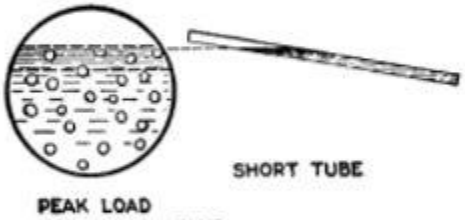
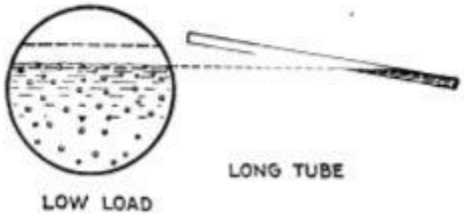


FIG. 2



3. The reason that the tube is inclined is to make it more sensitive to changes in the water level so that a slight decrease in water level will cause a proportional increase in the water flow to the boiler.

4. The feedwater valve lever should be directly above or directly below the thermostat lever. Use a plumb bob to ensure a straight vertical line.

5. The steam connection to the tube should come from near the top of the boiler. The steam line is run upward at a slope of not less than one inch per foot, so that any condensate that is formed in the steam connection is drained back into the boiler. You must bend this steam connection so that easy curves are formed without restriction. Regular pipe fittings cannot be used to make up the steam connection pipe.

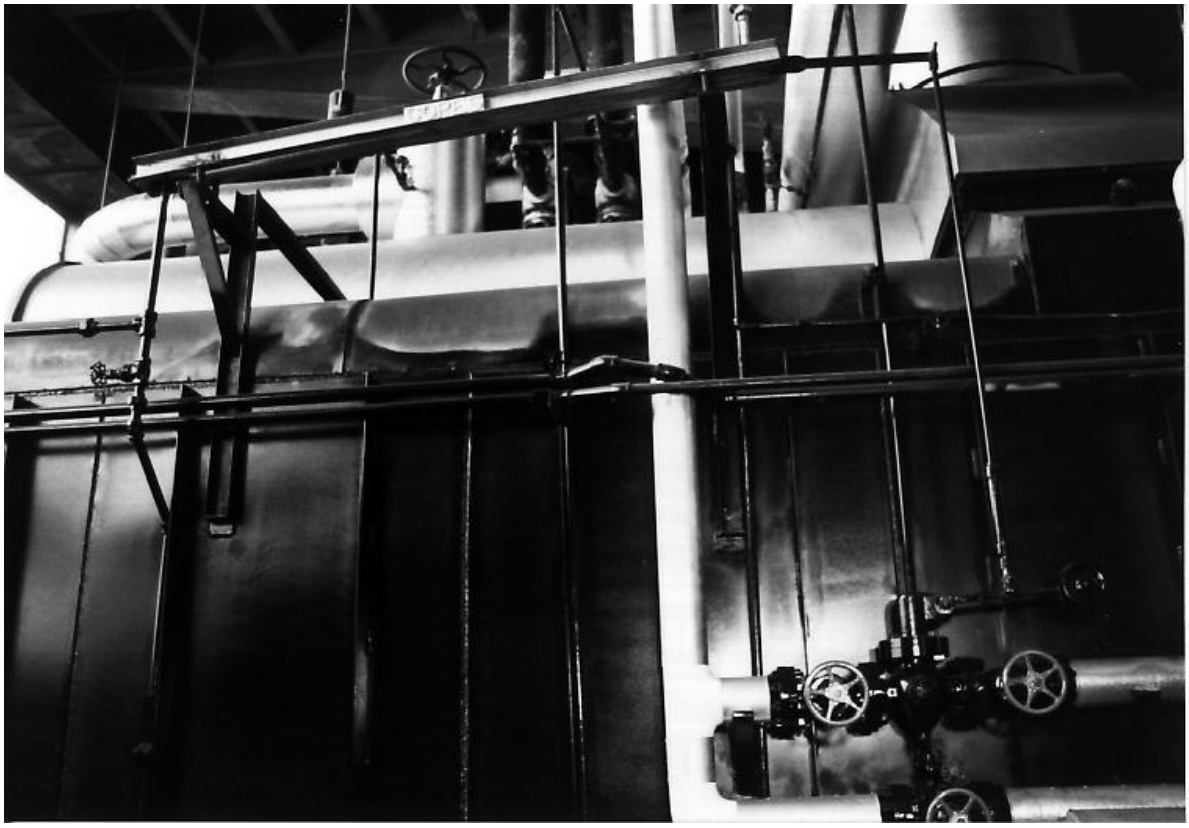
6. The water connection from the Copes tube runs straight down 6 to ten inches and then turns at a pipe tee to connect to the lower part of the boiler drum. The straight portion of the tee is extended with pipe to a valve which is used to blow down the Copes tube. A 3/4 inch pipe is used for both the steam and the water lines to the Copes tube. Pipe fittings (elbows and tees) can only be used in the water connection.

7. 3/4 inch gate valves are used in the steam line and in the water line to the Copes tube to isolate it for service, globe valves are never used. Unions or flanges are used to allow removal of the Copes tube.

8. NEVER paint, sand, or polish the thermostat tube. This will affect how the tube radiates heat and it will not operate correctly.

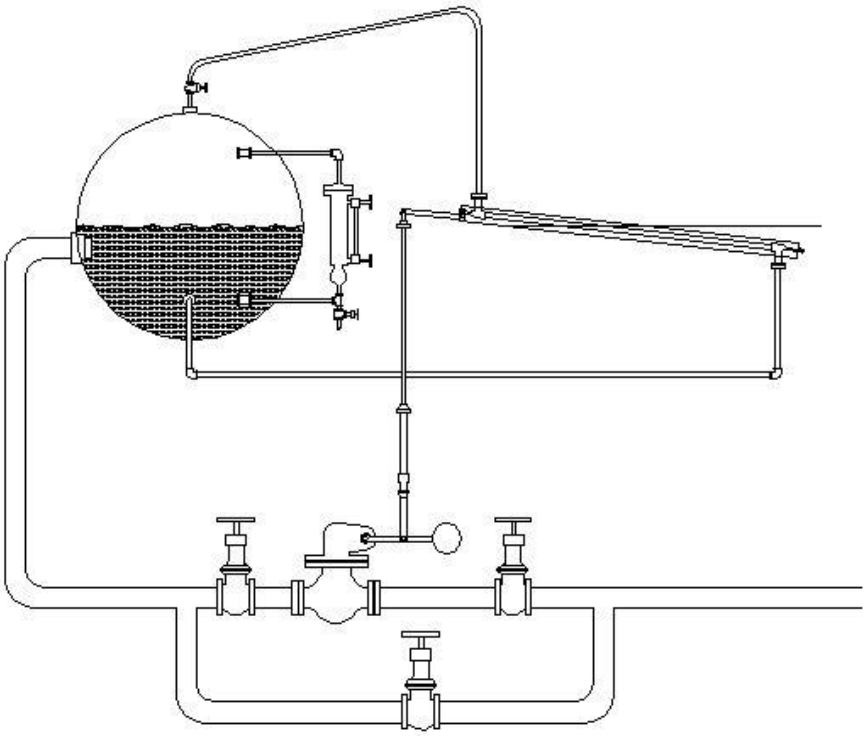
9. If the feedwater valve is below the Copes tube, then a tension relief is installed. If the feedwater valve is above the Copes tube, then some of the parts in the tension relief are turned around to make it a compression relief.

10. The position of the weighted valve lever indicates the amount of opening of the valve. The more the lever moves down, the greater the valve opening.



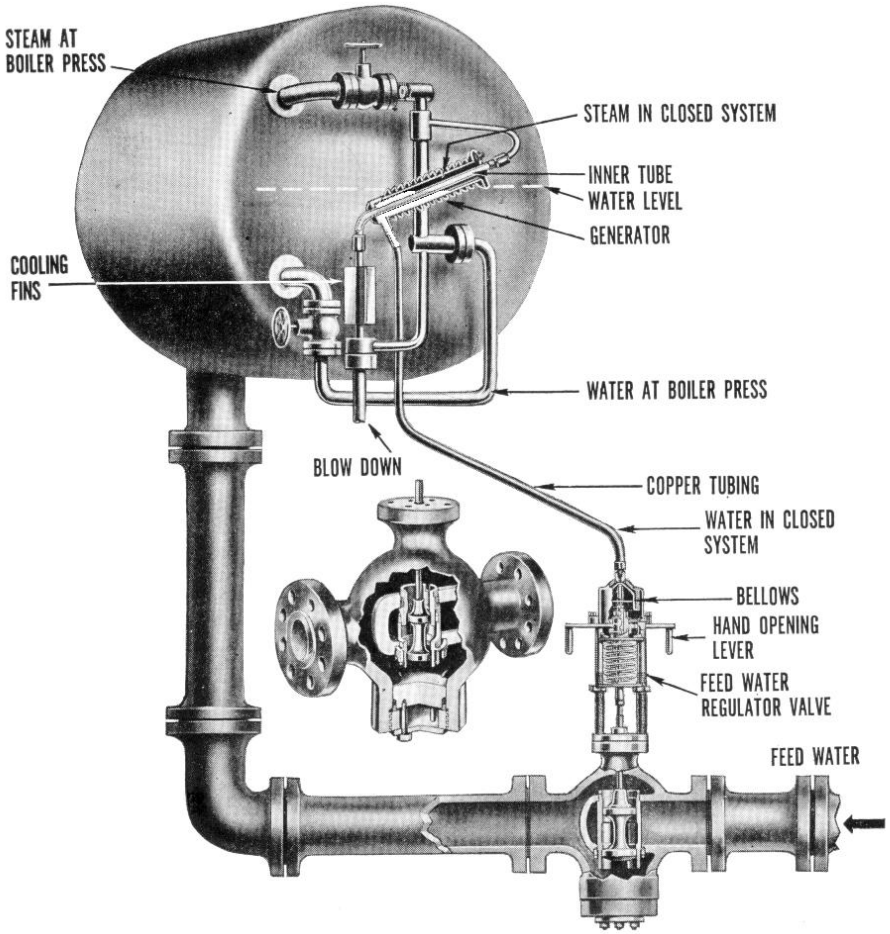
When the boiler is starting to rise in pressure but before it has started steaming, blow down the Copes tube by opening the blowdown valve on the lower end of the Copes tube. This will heat the tube and cause the feedwater valve to open wide. You must then throttle the water by hand to the boiler as it starts steaming until the Copes tube cools to its operating temperature. You will use the valve just before the feedwater valve to do this. The bypass valve is closed and all other valves leading to the boiler are open. You must watch the water level in the boiler and open the hand valve wider in response to the steam demand, to keep the water level at half-glass. After 15 to 30 minutes, opening the hand valve no longer affects the water level as the Copes tube has taken over and now the feedwater regulator will operate the water supply to the boiler in response to steam demand. Now open the hand valve wide.

The great thing about the Copes feedwater regulator is that once the tube is properly adjusted, it hardly ever needs re-adjustment. In order to adjust the Copes tube you must loosen the locknut on the lower end of the tube and then turn the nut closest to the tube. ONLY TURN THE NUT 1/6 OF A TURN OR ONE FLAT BEFORE RE-TIGHTENING THE LOCKNUT. Give the boiler time to react to your adjustment before you give the nut another 1/6 of a turn. The easy way to remember which way to turn the nut is to remember that it is just like turning a valve; turning the nut clockwise or to the right will tighten the nut and lower the water level in the boiler, turning the nut counter-clockwise or to the left will loosen the nut and raise the water level. Once the boiler is on the line you do not have to blow it down again except for once a week to make sure foreign matter is not building up in the tube. When the boiler is shut down you must close the hand valve in front of the regulator because the feedwater valve will not give a positive shut-off. The bypass valve is used to feed the boiler while the isolation valves are closed on either side of the feedwater valve to allow for service on the feedwater valve while the boiler is on the line.



You may have to draw a feedwater regulator for a boiler exam. This is a good drawing for that portion of the exam

BAILEY FEEDWATER REGULATOR

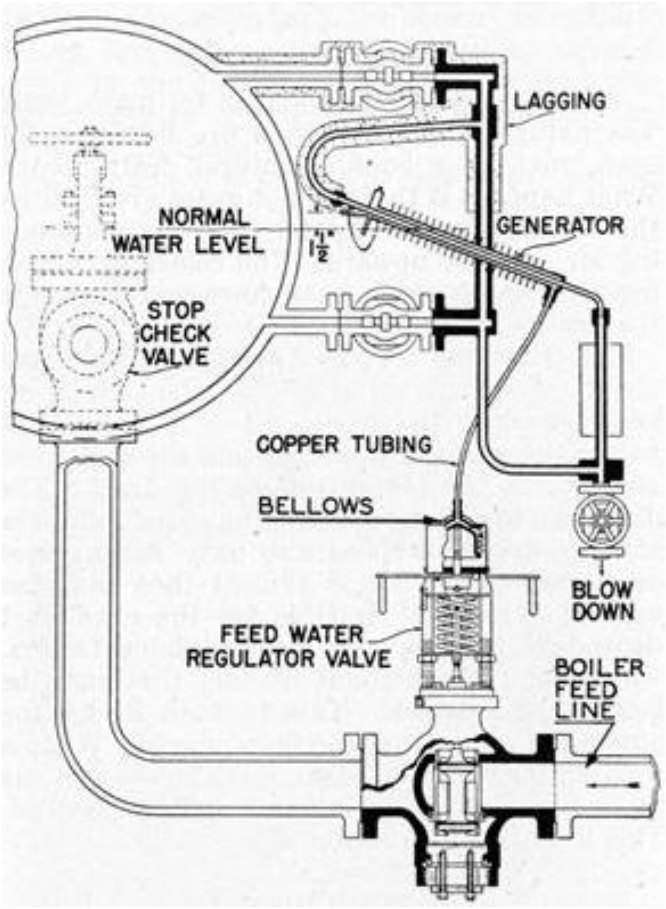


The Bailey feedwater regulator consists of a tube inside a tube. The inside tube is connected to top of the boiler drum for the steam connection and at the bottom of the drum for the water connection. The inside tube is set at an angle to the water level in the drum with the top of the tube set about two inches above the normal water level in the drum. The outside tube surrounds the inside tube and is completely full of water when the boiler is cold. Copper tubing connects the bottom end of the outer tube to the bellows at the top of the regulating valve. This water in the outer tube is completely separate from the water in the boiler. As steam is formed in the boiler, the water in the inner tube is at the same level as the boiler. The steam in the inner tube heats the water in the outer tube until the outer tube starts generating steam in the closed system. Since water compresses only slightly, the steam that is generating in the closed system of the outer tube exerts a pressure on the bellows at the feedwater valve and starts to open the valve. When the steam and water level in the outer tube is the same height as the steam and water level in the inner tube, and the feedwater rate matches the steaming rate. As the water level lowers in the inner tube, the heat in the steam boils more water in the outer tube, opening the feedwater valve more. The incoming feedwater in the boiler drum raises the level of water in the inner tube, cools the outer tube, causing steam in the outer tube to condense to water, reducing the pressure on the bellows and allows the feedwater valve to close down. The volume of water in the outer tube is measured so that when the water is at the top of the generator the valve is completely closed. When the water level is at the bottom of the generator, the valve is fully open.

Important points to remember about the Bailey Thermo-Hydraulic Feedwater Regulator are:

1. The valve can be installed anywhere in the feedwater line, and either horizontally or vertically because of the flexible copper tubing that connects the generator to the feedwater valve.

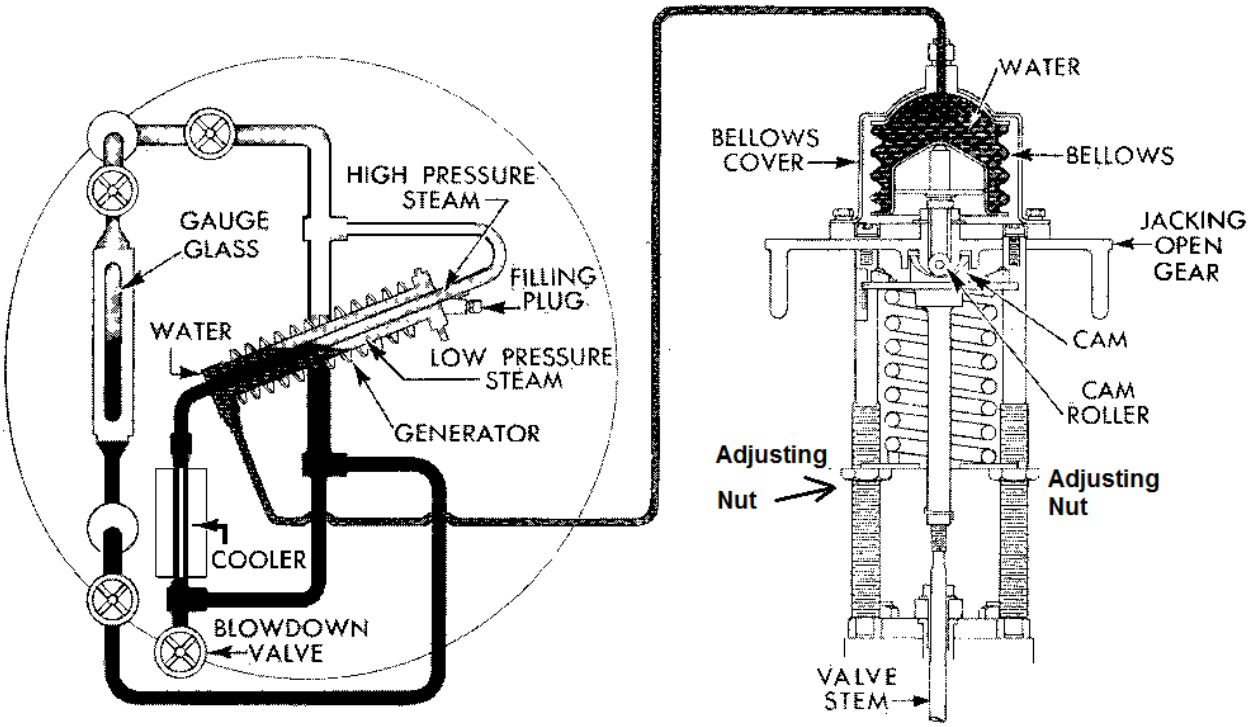
2. The use of the balanced valve in the feedwater valve prevents chattering and hunting.



3. A bypass lever is incorporated in the design of the feedwater valve.

4. A minimum force of 600 psi must be generated by the outer tube to operate the feedwater valve.

5. The hydraulic system is all metal construction with water as the hydraulic medium.



6. Turning the adjusting nuts on the feedwater valve toward the bellows tightens the spring and lowers the water level in the boiler. Turning the adjusting nuts away from the bellows loosens the spring tension and raises the water level in the boiler.

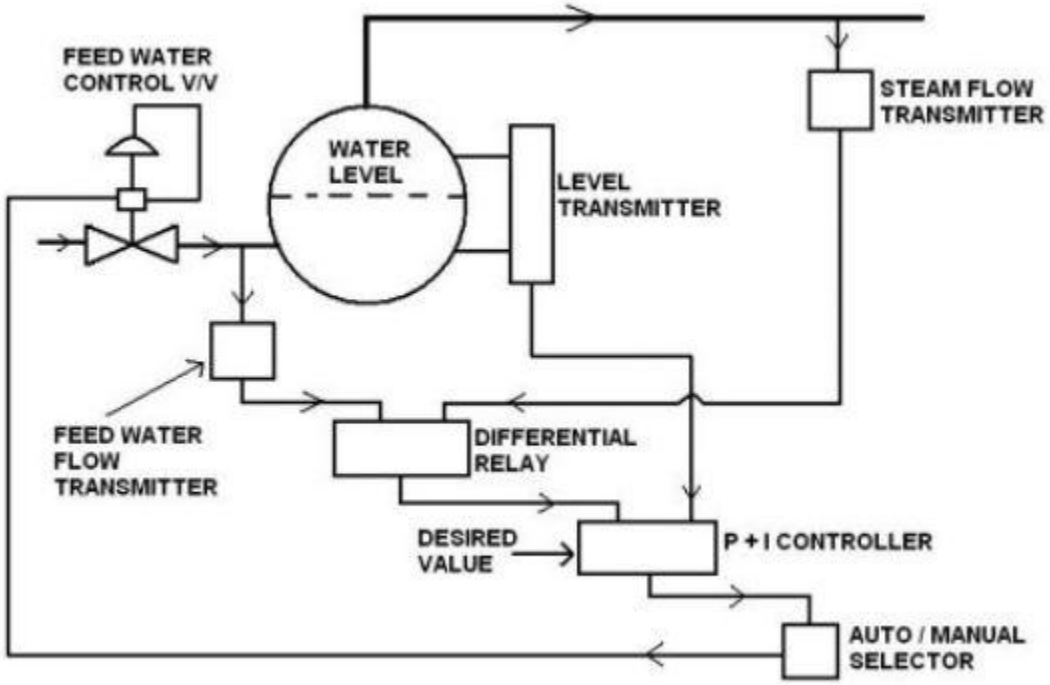
7. The packing gland nut should only be finger tight to avoid excessive friction on the valve stem.

8. If the bellows leaks on the regulator, the valve will fail in a closed position and not allow water into the boiler.

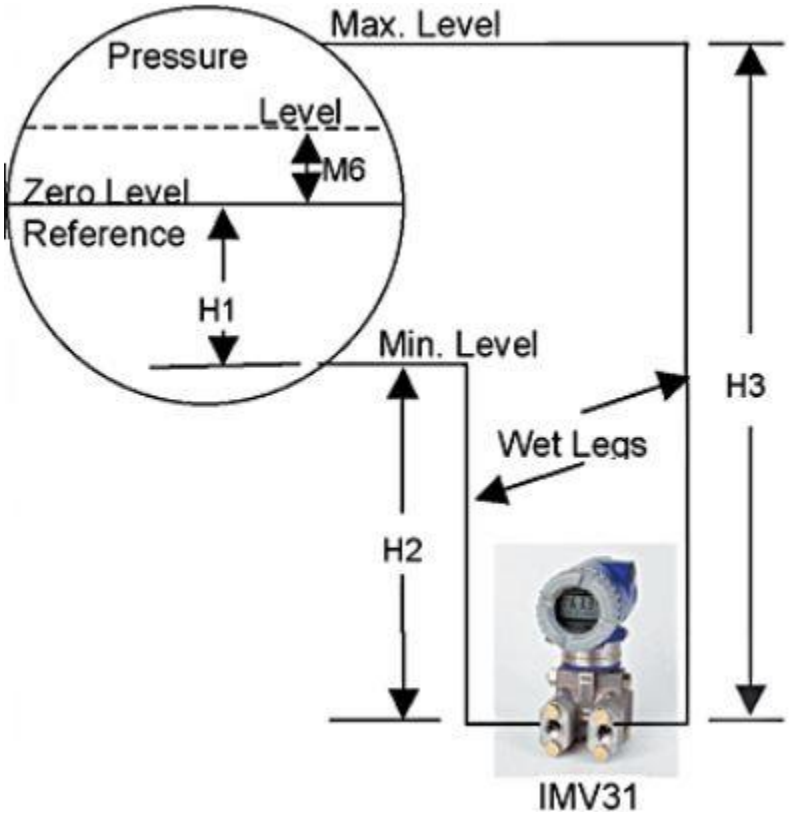
Bailey Generator

POWERED FEEDWATER REGULATOR

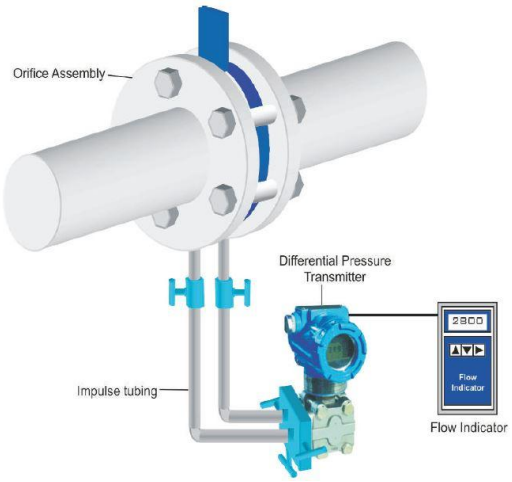
All the feedwater regulators discussed so far are self-powered. That means the level of the water in the boiler controls how much make-up water is allowed into the boiler. Floats, expanding metal, or hydraulic pressure directly control the make-up valve. Powered feedwater regulators include the two and three element feedwater regulators. These depend upon outside sources of power; pneumatics, electricity, or electronics to control the make-up valve. While these feedwater regulators have a greater accuracy in controlling water level and are essential in larger plants, they have one major disadvantage. When the source of power fails, the feedwater regulator fails. When the feedwater regulator fails the Operator must open and close the bypass valve by hand to keep water in the boiler until the problem is corrected. When the source of power fails the Operator will be busy enough trying to fix the other equipment without having to worry about operating the bypass on the feedwater regulator.



Let's look at the above diagram. There are three transmitters, steam flow, feedwater flow, and boiler level. For every pound of steam leaving the boiler, a pound of water should be going in. The differential relay computes the difference and sends it to the controller where the water level transmitter sends its signal to fine tune the water level. The output of the controller then goes through an auto/manual selector before the output is sent to the feedwater control valve. This system relies on electricity, electronics, air compressors and pneumatics to control the water level. Failure of any one of these systems means the feedwater regulator will not work. These items are illustrated on the next page.



Water Level Transmitter



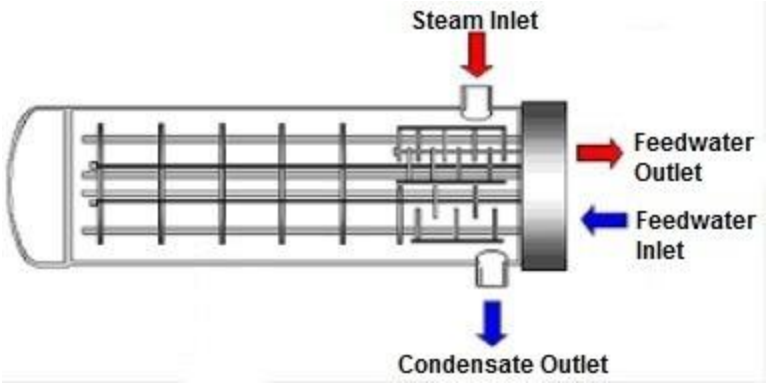
Steam Flow Transmitter

Feedwater Flow Transmitter

Controller

Pneumatically Operated Feedwater Control Valve

DEAERATORS AND FEEDWATER HEATERS

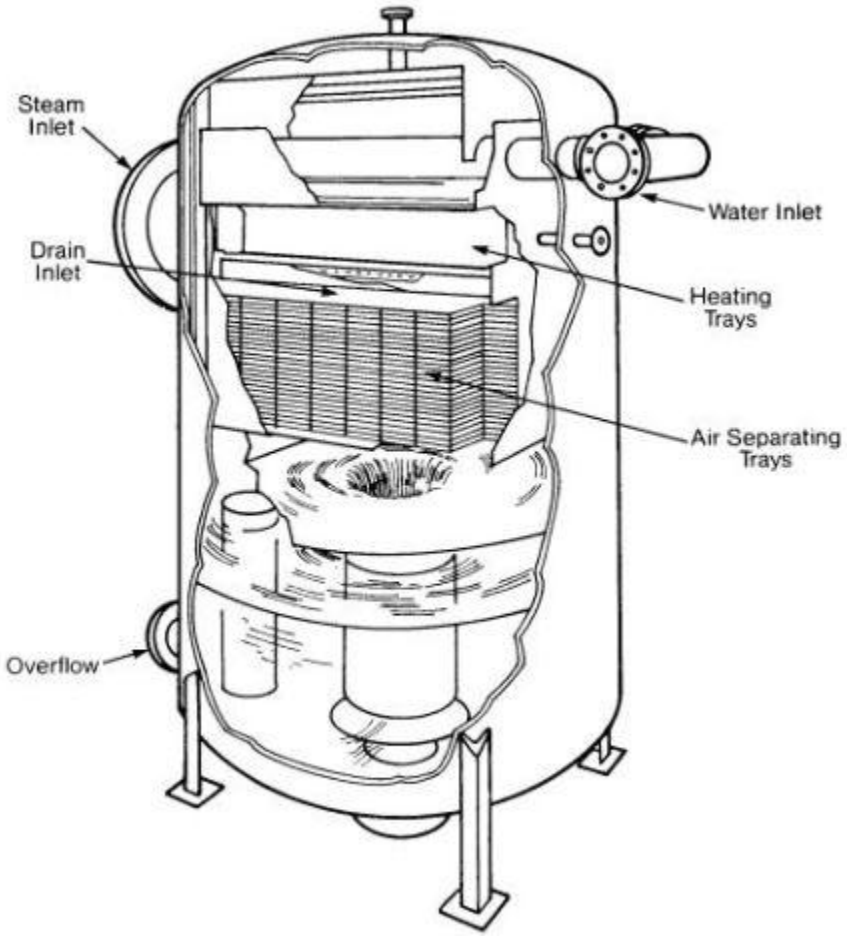


Feedwater heaters preheat the feedwater to increase economy and to prevent thermal shock. Preheating feedwater improves the economy of the boiler room by using exhaust steam to reduce the amount of fuel needed to bring the feedwater to boiling temperature. Feedwater is introduced into a boiler at the coolest part of the boiler to give it a chance to warm up to boiler temperature without causing thermal shock.

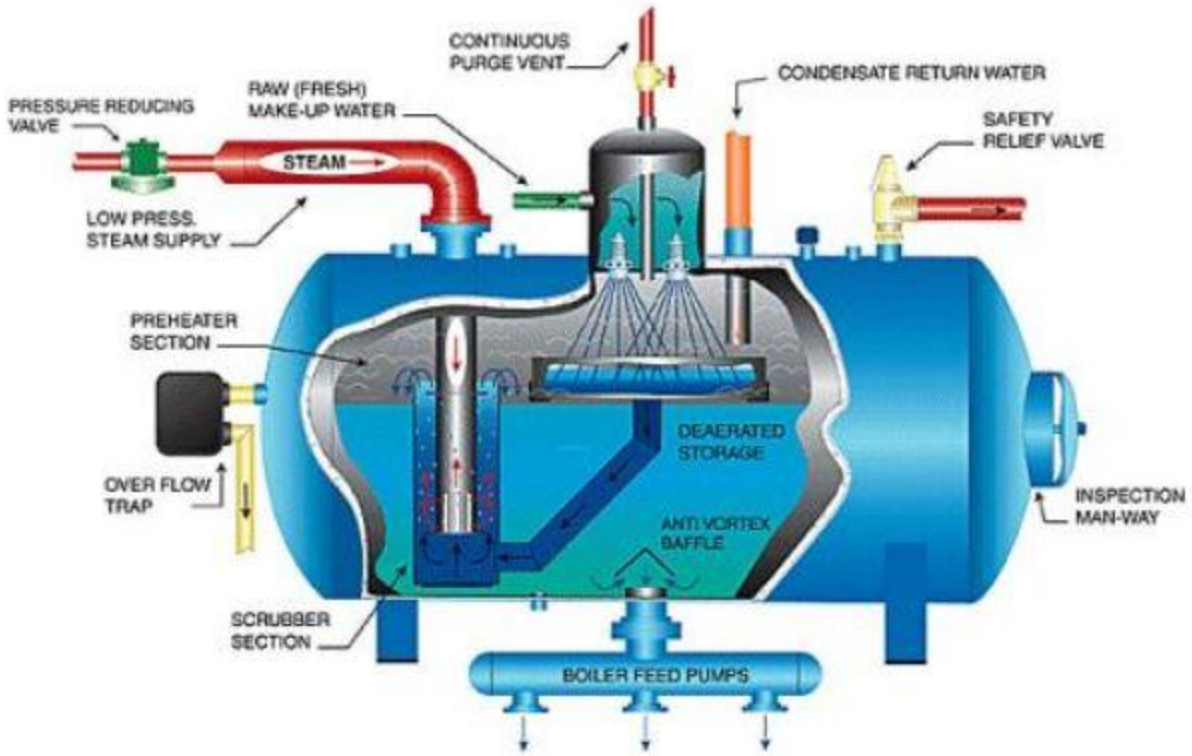
Thermal shock occurs when the incoming feedwater is too cold in relation to the temperature of the water in the boiler. Thermal shock can cause boilers to leak or even explode. During a low water condition in the boiler, if cold water were to hit the red hot overheated surfaces of boiler metal, the metal would contract suddenly and the boiler would tear apart at a weak point. This is why you never add feedwater to a boiler that has a low water condition.

Closed feedwater heaters

Feedwater heaters use exhaust steam from turbines and engines, or live steam from a reducing station to heat the incoming feedwater. If the heater is vented to the atmosphere, and the steam is in direct contact with the feedwater, then it is an open or deaerating heater. If the heater is not vented to the atmosphere and the steam does not come in direct contact with the feedwater, then it is a closed feedwater heater.



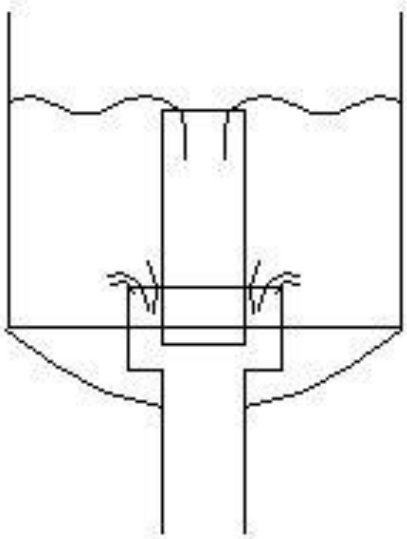
In an open feedwater heater, spray nozzles or stacks of trays are used inside the heater to break the incoming feedwater into small droplets that can be heated by the steam. The open feedwater heater stores a portion of the make-up water in the tank at all times. If the water level in the open heater gets too low, a make-up water line will add water to the heater. A filtering material such as coke or anthracite coal is sometimes placed at the bottom of the heater to catch impurities. The discharge of the open feedwater heater is at the bottom of the tank, usually directly to the boiler feedwater pump. The open feedwater tank is placed as high above the boiler feedwater pump as possible to prevent the flashing of water into steam at the pump suction. Air separates from the water in the tank. Air being lighter than steam rises to the top of the heater and escapes through a vent hole at the top of the heater. Some steam is lost with the air at the vent. A small tube bundle with the incoming feedwater inside the tubes is placed on top of the open heater just before the vent to condense the steam back into water. This small heat exchanger adds efficiency to the open heater and is referred to as a deaerating feedwater heater, although all open heaters will remove air from the feedwater.

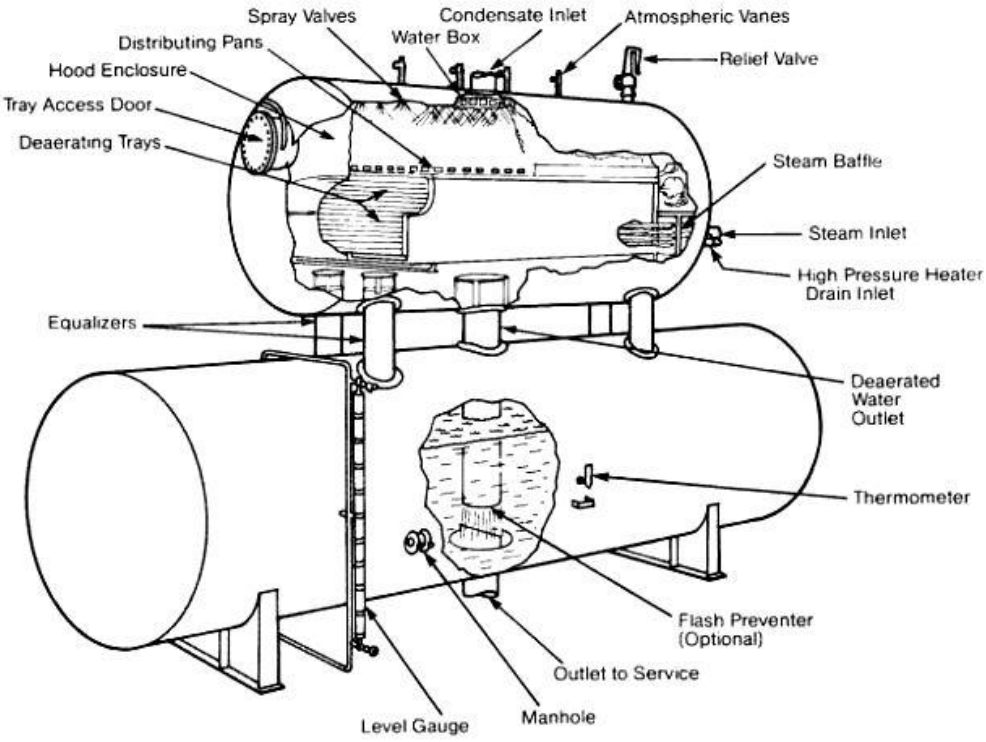


Air contains oxygen and carbon dioxide which will corrode the boiler steel. Removal of air from the feedwater is essential. Air gets into the feedwater through leaks in the piping in any part of the system that is below atmospheric pressure. After steam turns to condensate, the pumps that pull the condensate back to the condensate tank are often under a vacuum on the suction side. Removal of the air also helps control the Ph or alkalinity of the feedwater. Boiler water should always be alkaline or on the non-corrosive side of the Ph scale. On such a scale from 1 to 14 pure distilled water is neutral or at a Ph of 7. Anything less than 7 is acidic and anything greater than 7 is alkaline.

Important points to remember about open and closed feedwater heaters are:

1. The bottom discharge of the open feedwater heater sometimes has a smaller pipe that is centered in the larger opening at the bottom and is open at the top at the normal water level. This is known as a Vortex Eliminator. You are familiar with the small whirlpool or vortex that is formed in the bathtub when you pull the plug. The same thing happens in the bottom of the open feedwater heater and if the vortex extends to the pump suction, cavitation of the pump will result. Cavitation occurs when bubbles collapse at the pump impeller. Noise and damage to the impeller is the result. The water overflowing the smaller pipe at the top breaks up the vortex so that the boiler feedwater pump has a solid column of water at the suction.





2. By heating the water from 210 to 220 degrees in the open feedwater heater, the carbonates of lime and magnesium, referred to as temporary hardness, will come out of suspension in the heater rather than the boiler and form scale in the heater. This helps keep impurities out of the boiler where scale formation is a greater problem.

3. The open feedwater heater should be blown down once a day.

4. The pans in an open feedwater should be removed as needed to remove the scale buildup.

5. Accessories on an open feedwater heater are:

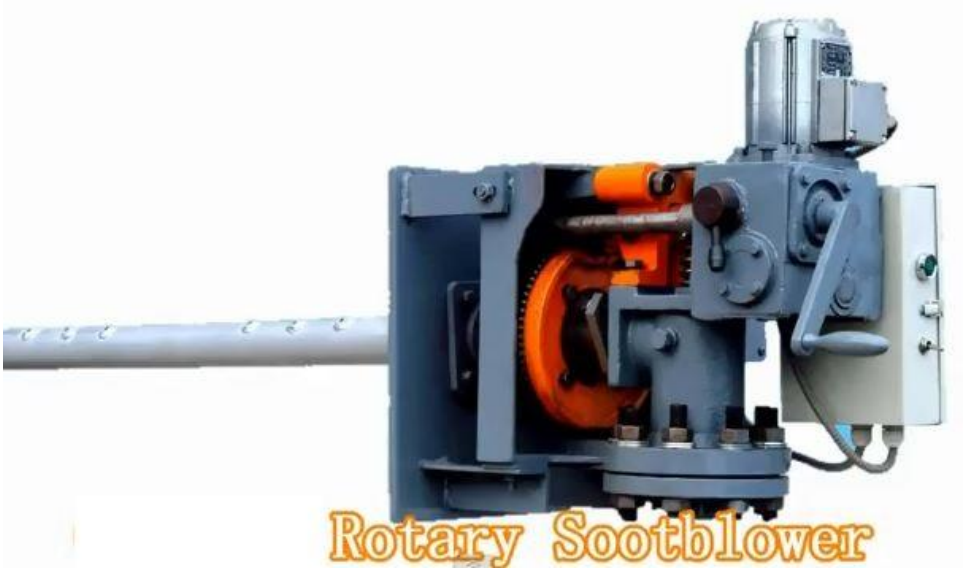
a. Gauge Glass
b. Relief Valve
c. Make-up Water Valve
d. Overflow
e. Pressure Gauge
f. Thermometer

6. In a closed feedwater heater, the water goes through the tubes and the steam surrounds the tubes. Condensate from the steam side of the heater is handled by a steam trap.

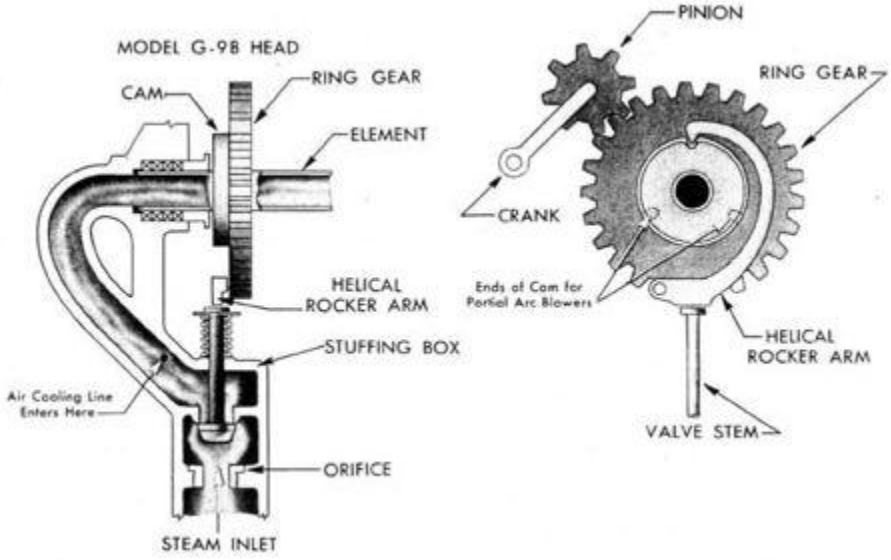
7. Closed feedwater heaters are not as efficient as the open type because the steam and water do not come in direct contact.

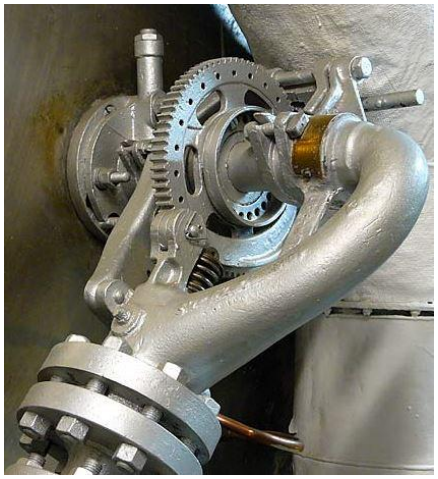
8. Oil cannot contaminate the feedwater in the closed heater as it can in the open heater.

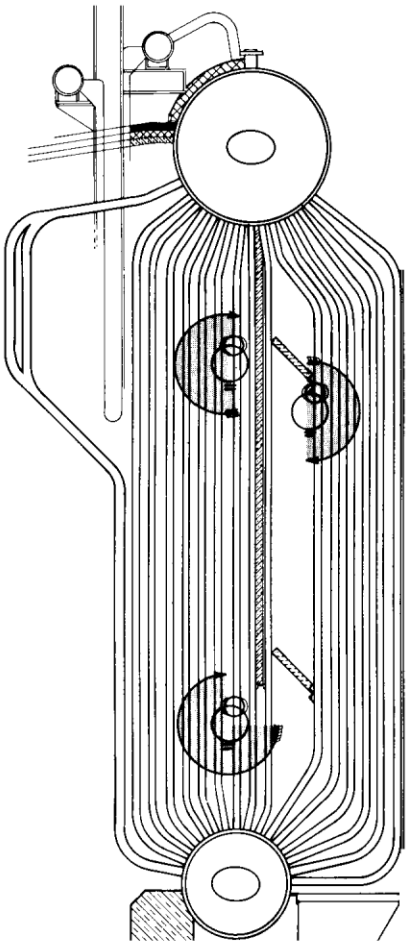
SOOT BLOWERS

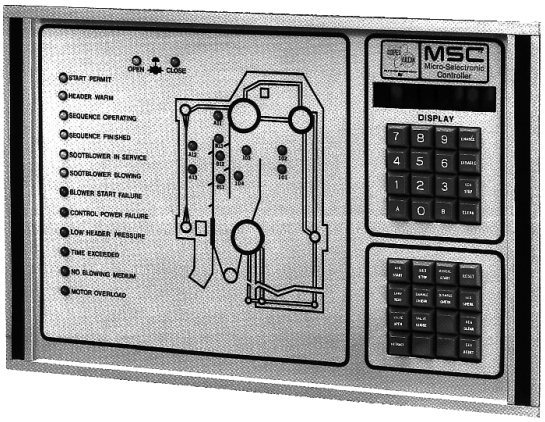


A sootblower is a device used to rid soot from the outside of water tubes, or the inside of fire tubes. As the combustion gasses cool down, the unburned carbon in the gasses can begin to build up on the tubes. Soot is an excellent insulator and this soot must be removed if the boiler is to operate efficiently. A sootblower is a long pipe with holes drilled at intervals so that compressed air or steam can be blown between the tubes and clean the tubes of soot. The reason the steam or air blows between the tubes is so that the high velocity jet will not cut the tubes. The sootblower is usually operated by chain valves that rotate the sootblower pipe in an arc so that the maximum surface can be cleaned. A cam attached to the wheel opens the steam or air when the when the holes in the pipe are in the right position.









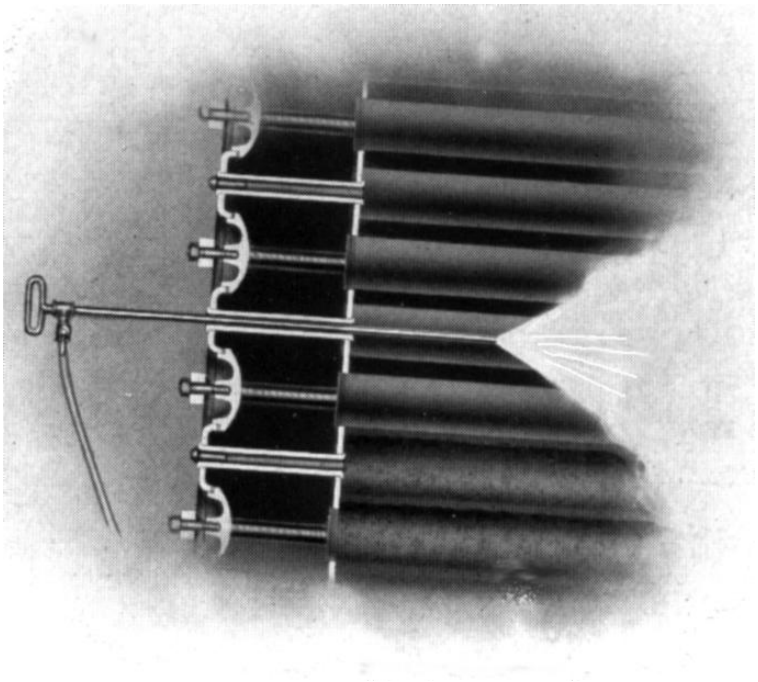
Soot blowers can be retractable and they can also be made to operate in sequence by an automatic controller.

Important points to remember about sootblowers are:

1. When sootblowing, the boiler is placed on manual in high fire to get enough velocity of air and combustion gasses travelling through the furnace to prevent a flame failure or a furnace explosion from all the soot that is being cleaned off the tubes.

2. Always follow the gas pass. Start at the sootblower closest to the front of the furnace and work back toward the chimney. This is so you do not put soot back on tubes that you have just cleaned.

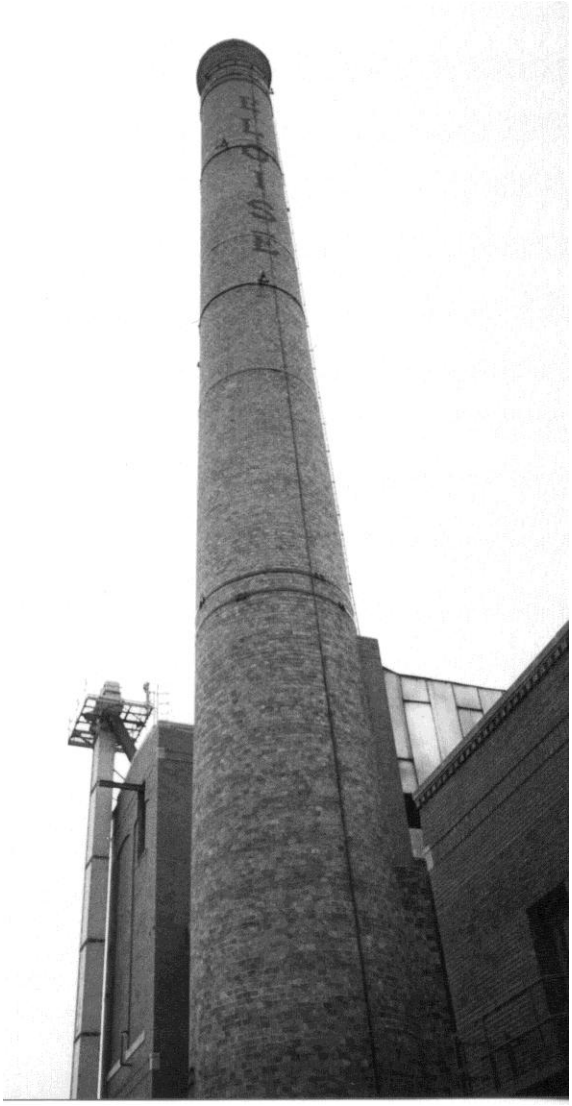
3. Before starting, drain the condensate from the line leading to the sootblower so that you do not throw water on the soot and cake the soot so that it will be harder to remove.



4. Steam lances, which are nothing more than a pipe connected to a steam resistant hose, are used to blow soot in small boilers or where permanently mounted soot blowers are impractical.

5. Blow soot at midnight when there is no moon outside and the Pollution Control man is asleep.

FANS, STACKS, and DRAFT



Drafts are produced by the rising combustion gases in the stack, flue, or by mechanical means. Draft can be put into four categories: natural, forced, induced, and balanced.

Natural draft: When air or flue gases flow due to the difference in density of the hot flue gases and cooler ambient gases. The difference in density creates a pressure differential that moves the hotter flue gases into the cooler surroundings.

Forced draft: When air or flue gases are maintained above atmospheric pressure. Normally it is done with the help of a forced draft fan.

Induced draft: When air or flue gases flow under the effect of a gradually decreasing pressure below atmospheric. In this case, the system is said to operate under induced draft. The stacks (or chimneys) provide sufficient natural draft to meet the low draft loss needs. In order to meet higher pressure differentials caused by pollution control equipment, the chimneys must simultaneously operate with induced draft fans.

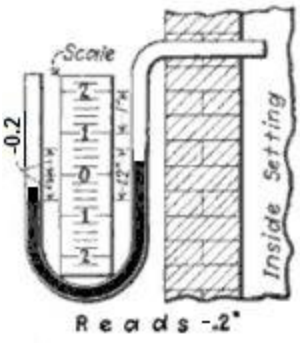
Balanced draft: When the static pressure is equal to the atmospheric pressure, the system is referred to as balanced draft. Draft is said to be zero in this system.

The basic principle of natural or chimney draft pressure is when that a lighter gas is submerged in a heavier one, the lighter gas is forced upward by the heavier. A hot air balloon ascends in a cooler atmosphere. It is due to the same fundamental principle that a chimney produces the draft pressure which forces the draft through the boiler furnace setting. A difference in temperature forces hot air up a chimney in a natural draft furnace, not the air blowing across the top creating a vacuum.

The function of draft is to force air to the fire and to carry way the gaseous products of combustion. Proper combustion in a furnace can occur only when the necessary supply of oxygen is supplied to the burning fuel. If the supply of oxygen is insufficient, the combustion will be sluggish and inefficient, even with well designed furnace construction and the most efficient burner.

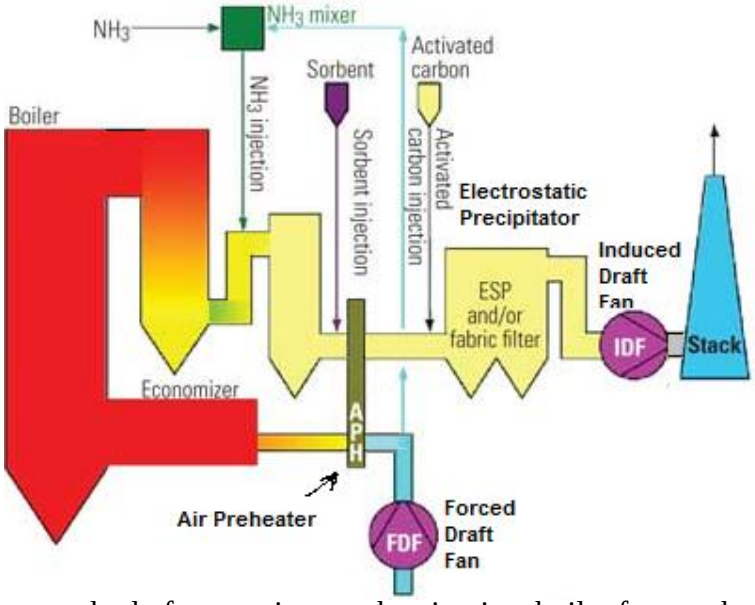
Draft is understood universally to relate to the movement of gases through a furnace, boiler, and chimney. Sometimes it is used to indicate the volume of gases moved. The term draft is used frequently to denote the air pressure which produces the movement. For this discussion, Draft will mean the quantity of air which is forced through a furnace in a given time. The term of draft pressure will mean the pressure which causes the gases to move.

The quantity of draft air may be substantial, when sufficient air is supplied to the furnace for combustion, even though the draft pressure is small, as shown by a draft pressure gauge which reads only -0.2 inches of water column. Draft pressure is measured in inches of water column it is the most convenient unit to express small pressures. 27.7 inches of water equal 1 psi. Furnace draft can be -.02 to -.05. A draft pressure gauge reading of .2 inches of water column means that the draft pressure tending to force outside in air into the stack or boiler at any point at which the reading is taken is just sufficient to support a column of water .2 inches high.



A simple manometer or draft pressure gauge is merely a glass of any convenient diameter having a U a shaped bend it in one end. The U portion is filled partially with water. One end of the tube is extended into the enclosed space, the draft pressure into which it is desire to measure. The other and is open to the atmosphere. When there is no difference in pressure between the two ends of the tube, the water will rest at the same level in both legs. If the atmospheric pressure tends to force air into the enclosed space, the water is forced up. The weight of the cool atmosphere column acts against the weight of the lighter, hot air column and forces it up, until the unbalanced height of the water column just equals the difference in the weights

The draft developed must be sufficient to overcome the draft losses due to the fuel bed, the first, second, and third flue gas passes, lengths of straight ductwork runs, any turns or elbows, dampers, economizers, baghouses, electrostatic precipitators, and other pollution control equipment. The sum of all available draft pressure drops must be equal the effective draft pressure provided by the fans and chimney.



Balanced draft is a method of promoting combustion in a boiler furnace by means of blending a forced draft fan with an induced draft fan with a stack or chimney. The purpose of the balanced raft is to economize the process of combustion by eliminating the necessity for admitting large quantities of excess air into the furnace. The forced and induced drafts are adjusted automatically, by means of dampers and fan controlling devices so that only sufficient velocity of flow to carry the gases in the direction of the chimney exits the combustion chamber

The total draft pressure developed by a chimney is the total pressure which results due to the difference in the weights of the column of hot glue gas inside the chimney and a column of the outside air of the same area and height.

Chimney draft is due to pressure. The impression that it is due to a vacuum is erroneous. A draft pressure gauge reading indicates the pressure of the cold outside air to force its way into the chimney through the boiler and furnace setting. The function of a chimney is two-fold.

1. It produces the draft pressure, whereby the draft is forced through the furnace, fuel and setting. The air which carries the oxygen, necessary for the proper combustion, burning of the fuel, is thereby furnished to the fuel bed.

2. It carries the products of combustion to such a height, before discharging them that they will not be objectionable to the immediate surroundings.
Many smaller boilers sold today used a forced draft fan in an airtight casing. It is more economical to build and erect at the Plant location. Forced draft fans are always used with underfeed stokers.

The words "stack" and "chimney" are used interchangeably now but older Engineering texts referred to Chimneys as tall brick or masonry structures, while Stacks were of shorter sheet metal construction.

Draft is measured with various types of draft gauges that measure low pressures

Induced draft fans are larger than forced draft fans because of the increased volume of hot flue gasses. The Induced draft fan runs slower than the forced draft fan. Fan interlock switches prevent the burner from starting if the fans are not running. Air pressure switches are better than electrical contacts that prove the motor is running. The coupling may have sheared and the fan itself is not running.

Forced Draft Fan

Backwardly-Inclined Airfoil Wheel

A forced draft fan is typical a backwardly-inclined airfoil wheel used for forced-draft boilers or balanced-draft boilers. This type of fan is preferable because it typically is high volume, and handles clean air.

Radial Tip Wheel

Induced Draft Fan

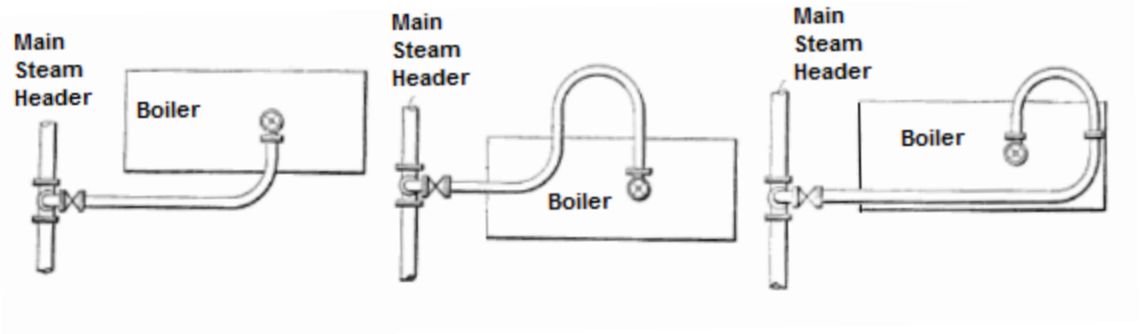
Flat Blade Backwardly-Inclined Wheel

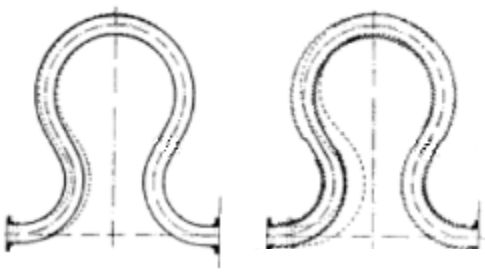
Induced Draft fans are illustrated above. Radial-blade fans were at one time commonly used for induced draft service. However, as pollution requirements have become more stringent and control devices have been added to reduce flue gas particulates (ahead of the induced-draft fan), radial-tip blade or even backwardly-inclined fans have become popular due to their higher efficiencies and higher volumetric characteristics.

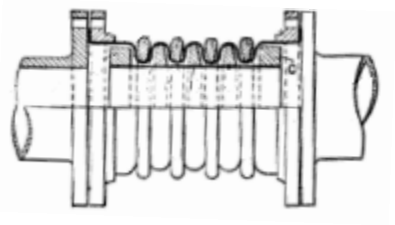
Forced and induced draft fans can have their outlet volume controlled by inlet dampers, inlet guide vanes, hydraulic couplings, variable frequency drives, magnetic couplings, and small steam turbines. Some Powerplant fans have an electric motor on one end of the shaft and a steam turbine on the other for flexibility in startup and emergency operation.

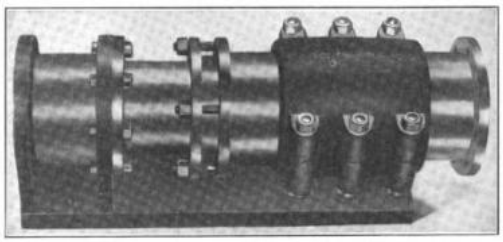
STEAM PIPE EXPANSION LOOPS and JOINTS

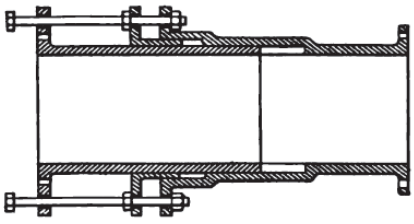
Steel pipe expands 1.5 inches every 100 feet going from 70 degrees F. to 270 degrees F. This expansion has to be taken care of by expansion joints or loops. The steam pipe has to be on rollers with curved plates between the roller and the pipe insulation so the pipe can expand and contract. Failure to do so will lead to rupture of the pipe. These are some of the ways Mechanical Engineers have designed solutions to take care of steam pipe expansion. Pipe bends, corrugations, and packing sleeves are some of the methods employed.

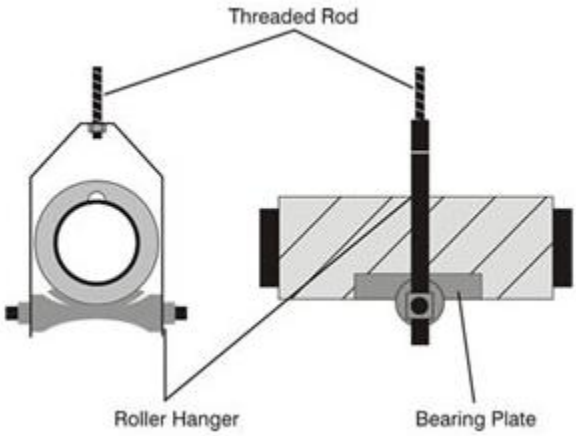




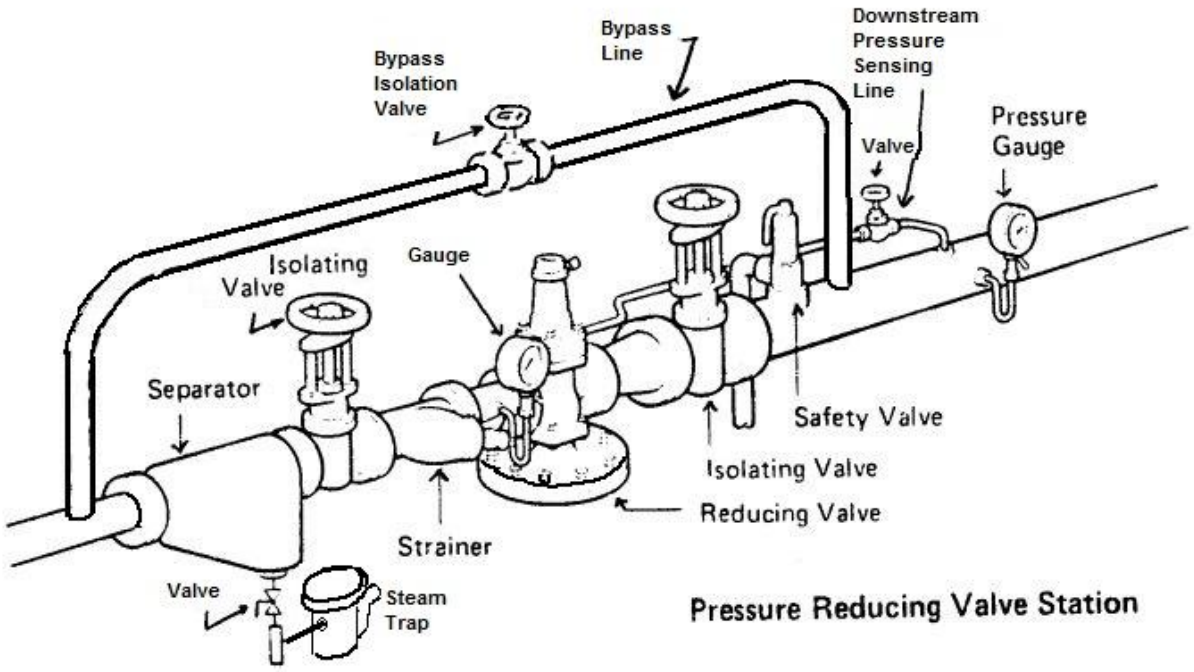








PRESSURE REDUCING STATIONS



There are situations where a lower steam pressure is needed than what the boiler is producing. An example would be a 150 psi steam process load with a 5 psi heating load. The Pressure Reducing Station can lower that pressure. The Pressure Reducing Station's temperature is a few degrees lower at the outlet, but the steam is superheated in relation to its new pressure.

The following considerations should be met:

1. Match the valve to the new lower pressure

To select the correct PRV for a given application, you need to know the maximum and minimum steam flow rates, as well as understand the turndown capabilities of the pneumatic control valve and/or regulating valve.
As a general rule of thumb, typical turndown ratios for select valve types include:
Regulator: 20 to 1
Globe valve: 30 to 1

2. Include a steam line drip pocket

All steam PRVs must have a condensate removal drip pocket piped upstream of the valve. The drip pocket removes condensate from the steam line, preventing condensate from passing through the valve. This is essential because condensate that enters the steam valve will cause erosion and shorten the life of the valve

3. Include a strainer with a blow-off valve

A strainer is also a requirement upstream of a steam Pressure Reducing Valve to protect the valve from debris that may clog the system. Steam lines frequently contain residual solid materials from corrosion in the steam line. The strainer will filter the steam stream and prevent this material from lodging within the valve, which could otherwise cause premature failure. The strainer should be rated for 20 holes per square inch perforated stainless steel mesh.

Never mount the strainer with the strainer segment in a down position; instead, install the strainer segment in a horizontal position. This will prevent condensate from accumulating in the strainer pocket and eventually passing through the Pressure Reducing Valve, thereby reducing the likelihood of internal erosion and premature valve failure. Finally, install a blow-off valve on the strainer to allow plant personnel to periodically clean out the strainer.

4. Position the pressure-reducing valve correctly

To extend the life of PRVs, always install them on horizontal steam lines, never vertically. A PRV in a vertical installation has no ability to eliminate the build-up of condensate prior to the valve's inlet. Condensate passing through a steam PRV always negatively affects the valve's life.

5. Use the bypass valves and warm-up valves

Bypass valves and warm-up valves should be used in all Pressure Reducing Valve installations. The warm-up valve warms the steam line within recommended time frames for the steam line. The warm-up is modulated and controlled during the start-up procedure. A steam PRV should not be used for warming up a steam distribution line.

6. Make sure to install a safety valve

Safety valves are an important consideration in a steam Pressure Reducing Valve station. But they may not be required in every case. If any steam component or the steam line downstream of the steam Pressure Reducing Valve is not rated for the maximum inlet steam pressure to the Pressure Reducing Valve station, then a safety valve must be installed to protect the system. When installing a safety valve, be sure the discharge is piped to a location where it will not pose a safety risk for plant personnel.

7. Install before and after pressure gauges

It is always good practice to install pressure gauges before and after the steam Pressure Reducing Valve as diagnostic tools. Be sure to include a siphon pipe and isolation valve for maintenance purposes.

8. Establish a Standard Operating Procedure

Every Pressure Reducing Valve station requires a Standard Operating Procedure to ensure that plant personnel are starting, operating, and shutting down the valve station correctly and safety.

Chapter 9 Questions

1. At what temperature does the fusible plug melt?
2. How thick must a tube be for a fusible plug?
3. What does a fusible plug have stamped on the tin?
4. Why is the water column called the "window" into the boiler?
5. When are two gauge glasses required?
6. What is the minimum pipe size of the piping from the boiler to the column?
7. What is the minimum size of the drain line from the water column?
8. What is the minimum size of the pipe connecting the water column to the gauge glass?
9. What is the minimum size of the drain on the gauge glass?
10. Up to what pressure can cast iron water columns be used?
11. Up to what pressure can ductile or malleable iron water columns be used?
12. How do the pipes from the boiler pitch to the column?
13. To how high a pressure can round gauge glasses be used?
14. Why are crosses used in making up pipe fittings to the water column?
15. Can you have valves on the pipes from the boiler to the column?
16. How can you tell if the water column and gauge glass are mounted correctly on the boiler?
17. At what pressure does the code allow a remote gauge glass?
18. What protects the steam gauge from too high a temperature?
19. What is the major component of the steam gauge?
20. What is the minimum and maximum blowdown pipe sizes for boilers over 100 square feet?
21. Why can't you use a globe or gate valve for a bottom blowdown valve?
22. At what pressure must you have two blowdown valves?
23. Why do you open the valves wide when blowing down the boiler?
24. What is the purpose of the syphon breaker on the blowdown tank?
25. How big must the blowdown tank be?
26. How much bigger in area must the vent be than the outlet pipe of the blowdown tank? Why?
27. Can a blowdown tank be buried?
28. How does a Copes feedwater regulator operate?
29. Why is the Copes tube inclined?
30. Does it matter where the Copes tube is placed?
31. How do you adjust the water level when using the Copes tube?
32. How does the Bailey feedwater regulator operate?
33. How do you adjust the water level in the boiler when using the Bailey feedwater regulator?
34. How does a feedwater heater work?
35. How often should the open heater be blown down?

Chapter 10

VALVES, TUBES and PIPING

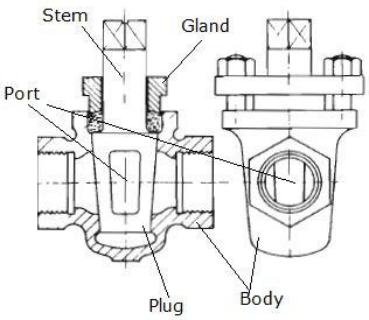
In order to control the flow of steam, water, and fuel in the boiler room, valves are used. The most common types of valves are:

1. Globe Valve
2. Gate Valve
3. Check Valve

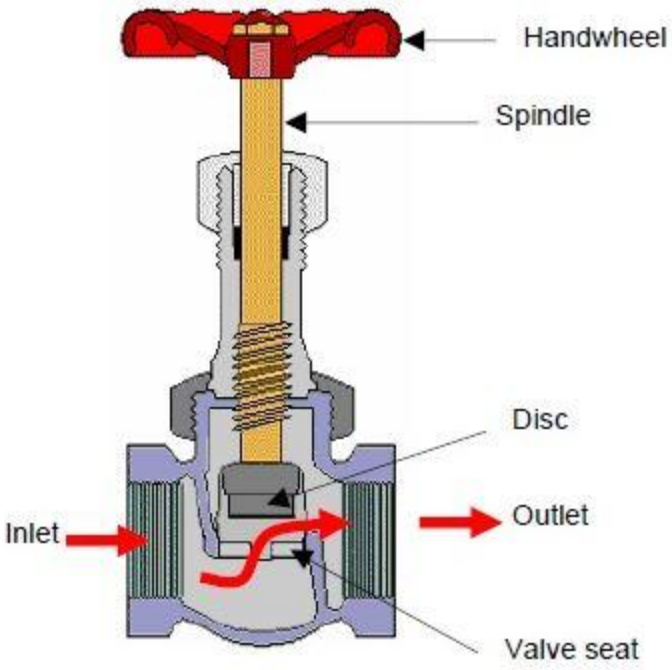
Specialized valves are used to finely regulate steam, feedwater and fuel. These valves include:

1. Balanced Valves
2. Reducing Stations
3. Feedwater Control Valves
4. Needle Valves

The ASME Code used to state that any steam outlet valve from the boiler over 2 inches in diameter must be of the outside screw and yoke type or a plug-cock type with the plug held in place with a guard or gland and with the handle indicating whether the valve is open or closed.

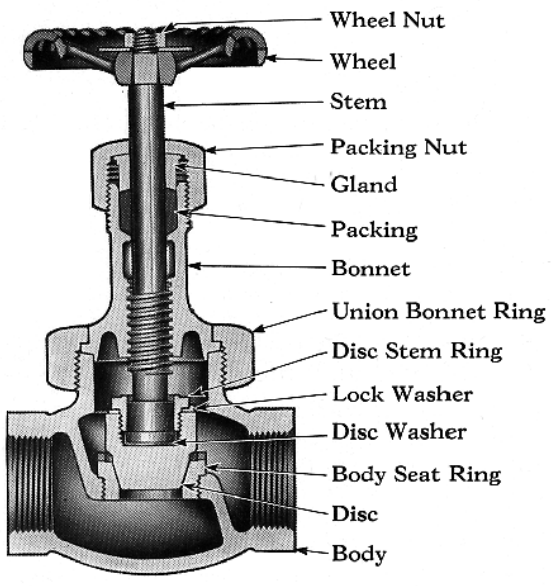


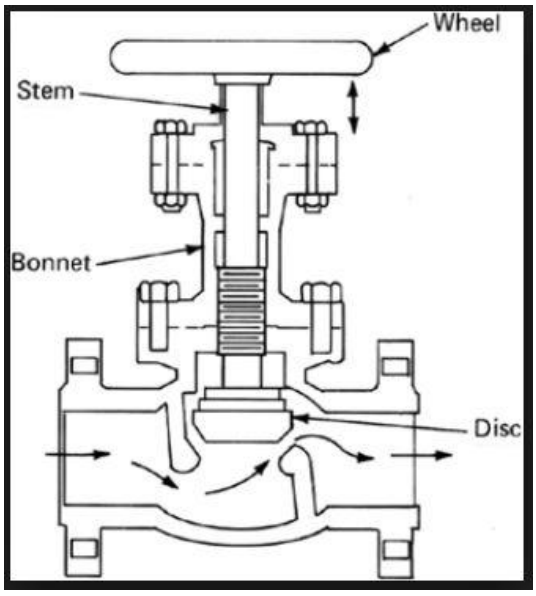
GLOBE VALVE



The globe valve has a flat seated horizontal disk on the end of a valve stem that fits onto a circular seat in the valve body. The globe valve can also have a cone shaped disk that fits into a tapered seat in the valve body.

Globe Valves are normally used when you need to restrict or regulate the flow through the valve.



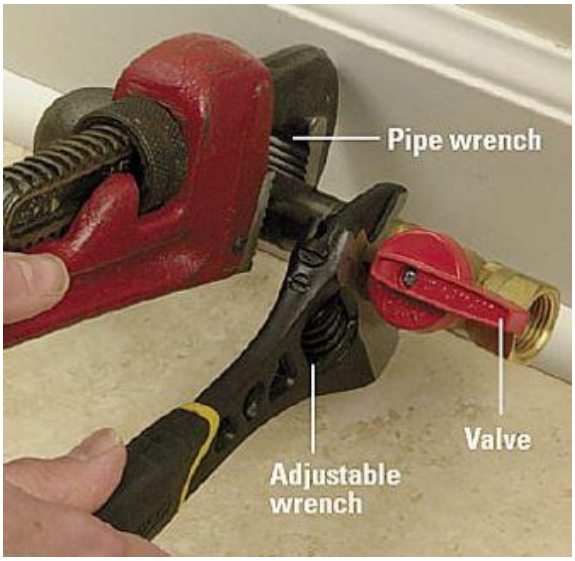


Notes on Globe Valves:

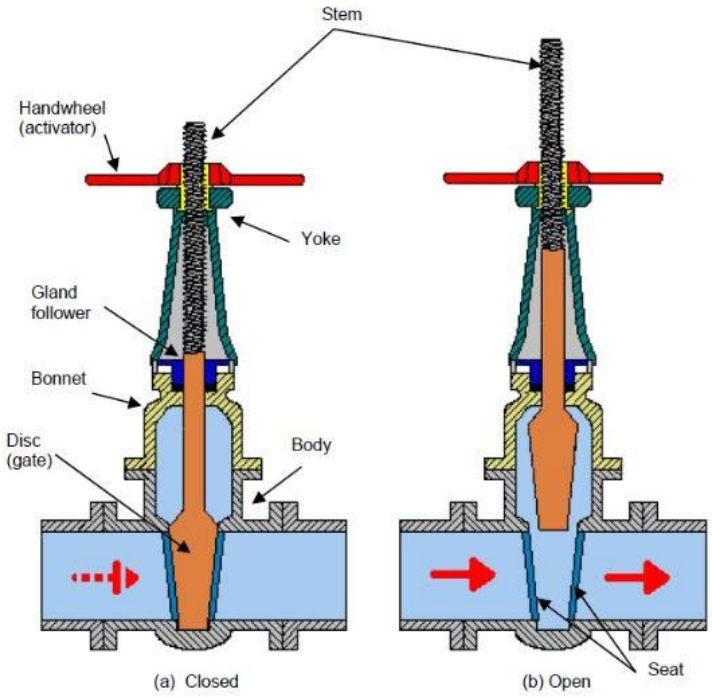
1. The valves are easier to repair than gate valves. The disks can be replaced on the valve steam easily and if the seat needs to be reground, it can be done without removing the valve body from the piping.

2. When used for critical service, such as feedwater supply, the water must come up under the seat. The reason for this is that if the disk came loose from the stem, the feedwater pressure would force the disk open. If the pressure were on top of the disk, it might hold the disk shut.

3. When installing a threaded globe valve, it is best to close the valve on its seat so that the stress on the valve body will not distort the valve seat. Sometimes this is not possible because of interference with pipes around the valve. You then have to remove the bonnet to get enough clearance to turn the valve. Always turn the valve body with the wrench on the end closest to the pipe. A smooth jawed wrench can tighten the valve if there are flats on the end without marring the valve like a pipe wrench does.

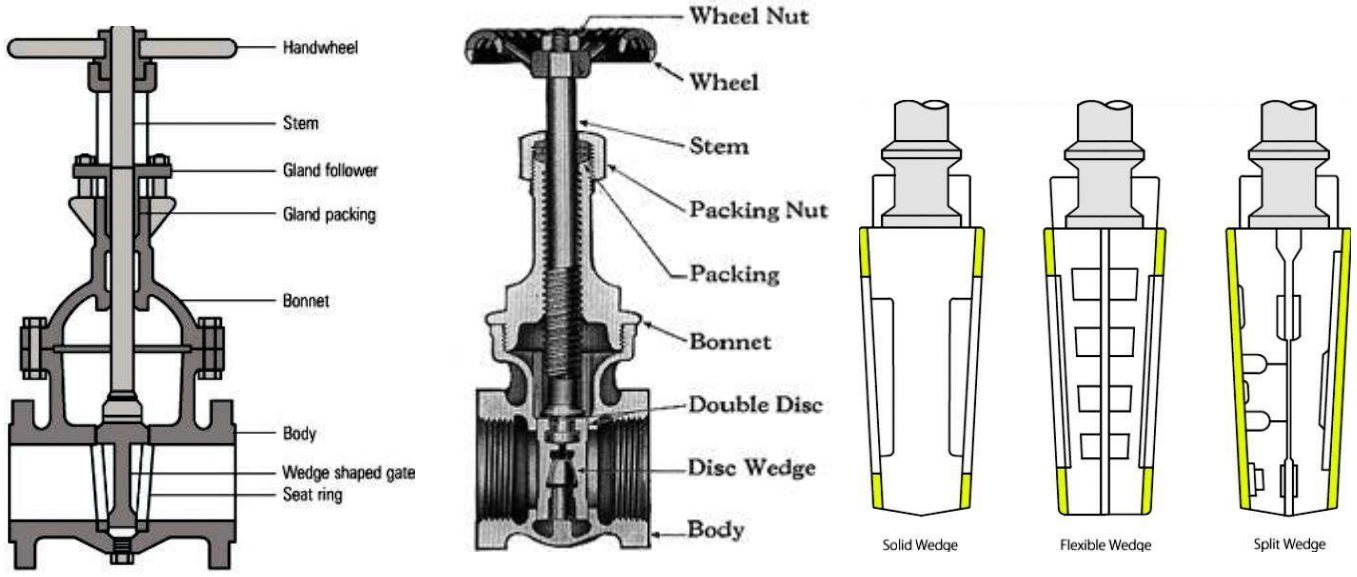


GATE VALVES



The gate valve has a wedge shaped vertical disk connected to the valve stem. The screw thread on the stem lifts the disk straight up or else forces it straight down on its seat.

Notes on Gate Valves:

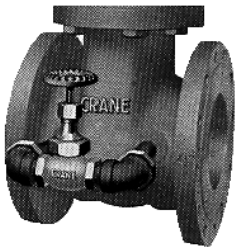


1. The wedge shaped vertical disk is usually one piece in smaller valves and can be split into two halves in larger valves to allow it to seat tighter. They must be installed vertically.

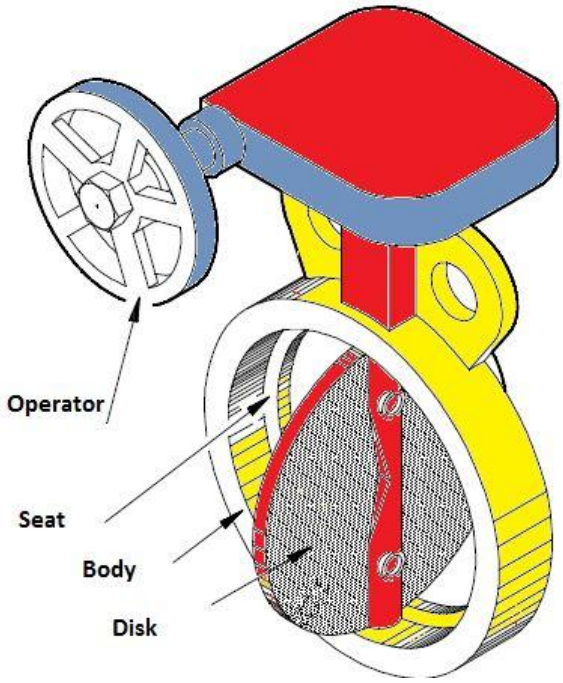
2. Gates Valves have less pressure drop across the valve when wide open than globe valves because the liquid can go straight through the open passageway.

3. The Gate Valve should never be used to throttle flow like the globe valve. You will wear the sealing edges of the valve disk and the valve will not seat properly.

4. On large globe or gate valves, bypasses should be provided around the valve to allow the valve to open with equal pressures on either side of the valve. The valve can be difficult to open and will wear the disk excessively as the high pressure steam blows past the bottom of the disk.

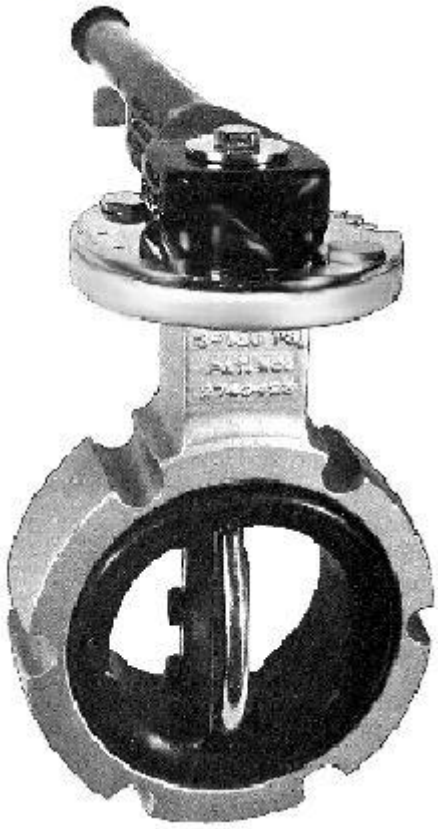


BUTTERFLY VALVES



Butterfly valves use a circular disk that pivots on a rod that goes through the center of the valve opening. When the valve is open, the thin disk is parallel to the flow and does not create much pressure drop across the valve. By turning the valve handle 90 degrees; the disk is spun on its axis to offer a full closure of the disk against its seat.

Butterfly Valve



Butterfly Valves can be built in large sizes

Notes on Butterfly Valves:

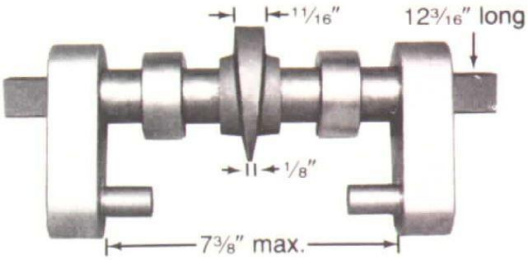
1. They take up minimal space in the pipeline.

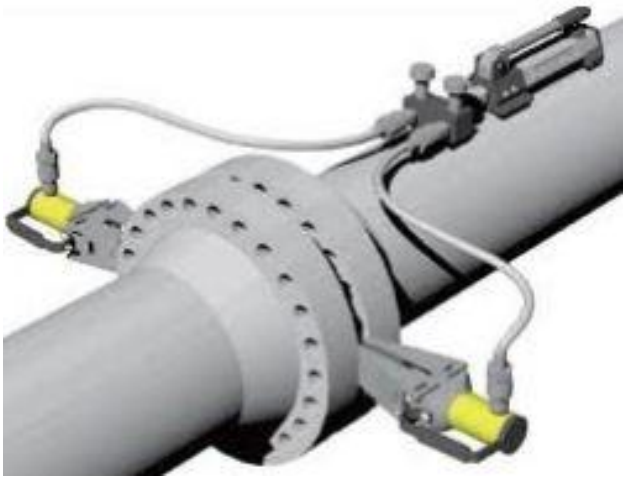
2. If they are flanged, they can be easily removed and replaced from the pipeline.

3. They can be used to throttle the flow of water, oil and gas.

4. For temperatures up to 300 degrees F and pressure up to 250 psi, ductile iron bodies use stainless steel disks with viton seats.

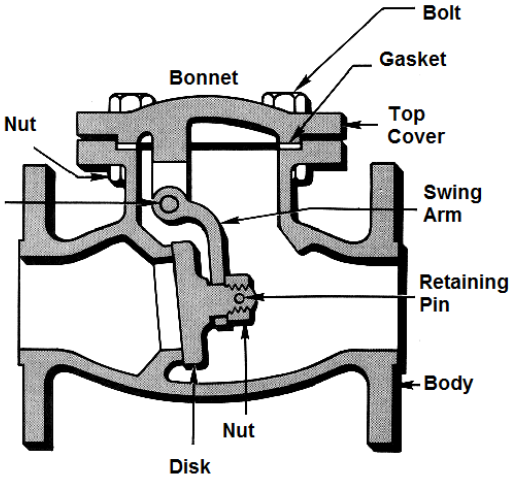
5. Like many pipeline valves, a flange splitter can help remove an old valve and install a new one. As the name implies, it spreads the flanges apart in order to slide the old valve out. It can be manually or hydraulically operated.





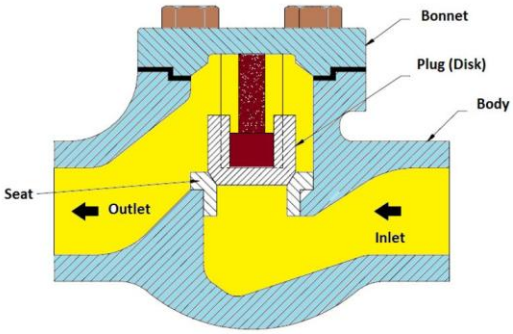
CHECK VALVES

Check valves are used to allow flow in one direction only. Any backward flow will or drop in pressure will close the check valve mechanism and prevent the water from going the wrong way. There are many different types of check valves. The three most common are the Swing Check, the Lift Check and the Ball Check.



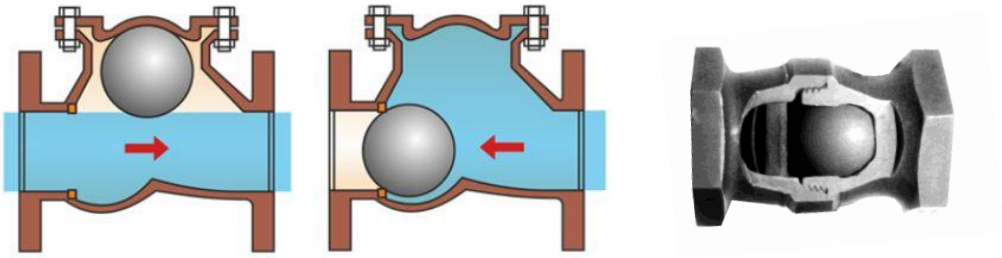
SWING CHECK

The swing check valve has a hinged disk that swings on a pin that acts as a pivot point. The valve body is marked with an arrow to show the proper direction of flow. They are usually mounted horizontally but they can be mounted vertically if the manufacturer design permits it. You must avoid mounting it on an angle that does not allow gravity to close the swinging disk.



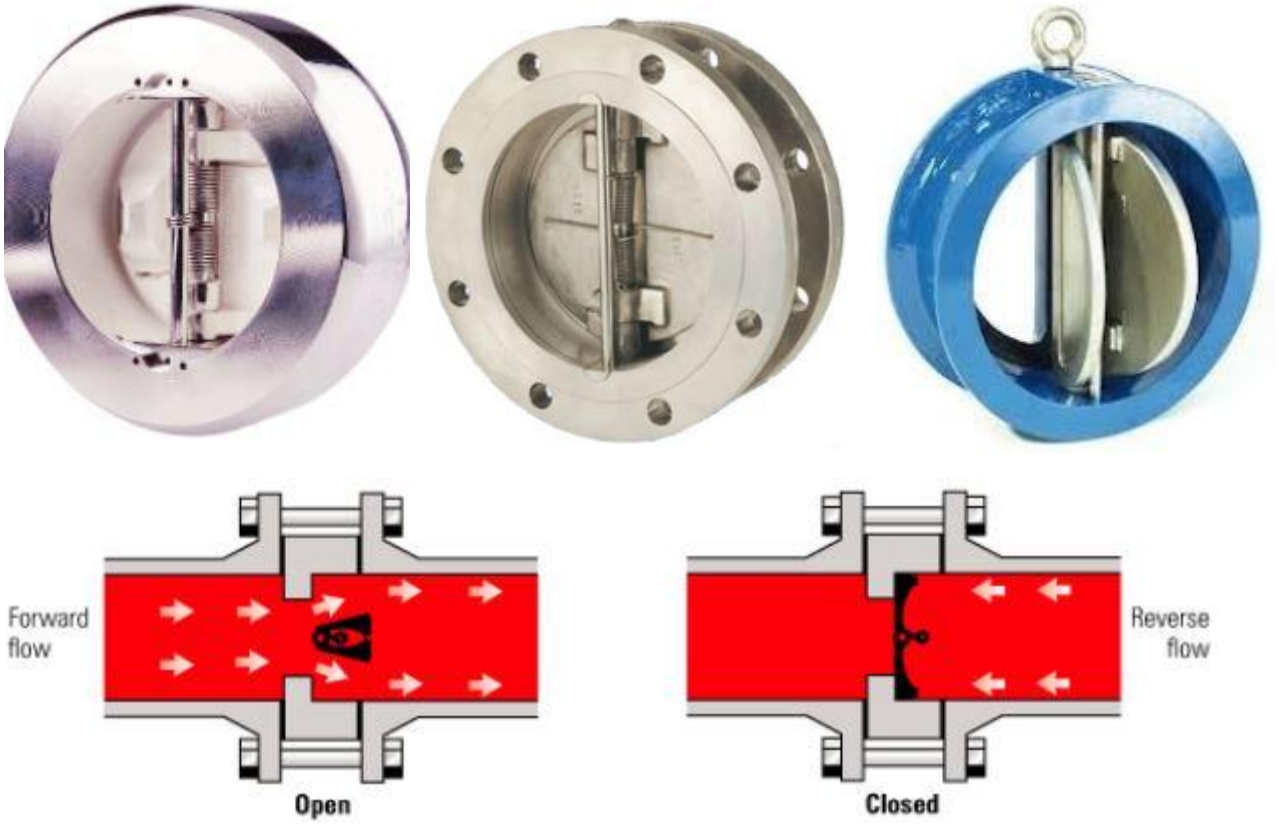
LIFT CHECK

The lift check is a horizontally mounted valve that is similar to a globe valve, without a stem. The flow underneath the horizontal circular disk lifts the disk from its seat. The seat travels straight up and down due to the design of the guides in the valve body. Some lift checks have springs to help the disc close on its seat.



BALL CHECK

The ball check uses a ball in a cage assembly that allows the ball to float freely as the liquid is going in the proper direction, but plugs the inlet with the ball should the flow reverse. They can be used in a horizontal or vertical position. Ball checks use a forged steel body with stainless steel balls for steam pressures up to 800 psi and temperatures up to 850 F.



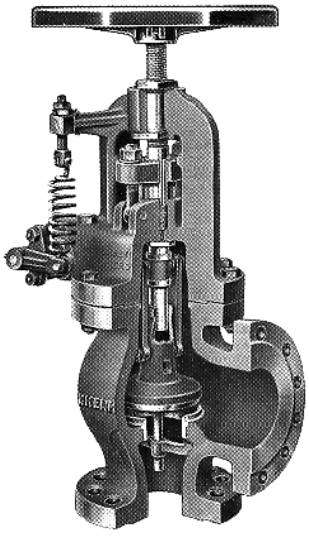
DUAL PLATE CHECK

Dual plate check valves are similar to butterfly valves that are split down a horizontal axis. They are hinged around the center pin and are spring loaded so that they close quickly. The quick closing action prevents surging and water hammer.

NONRETURN VALVES

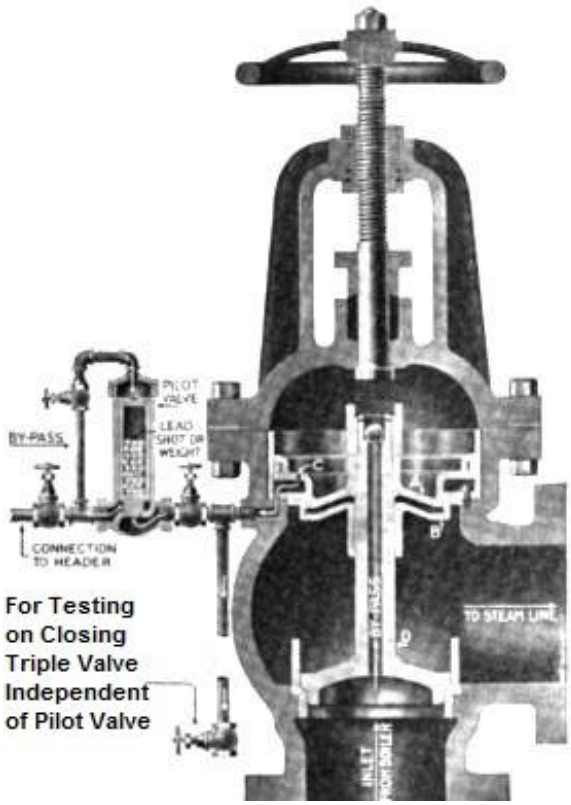
When there is more than one boiler attached to the same steam header, two main steam stop valves are required on each boiler, one of which may be a nonreturn valve. In practically all installations where there are boilers connected in battery, that is two or more boilers connected to the same steam header, the designer will specify nonreturn valves. The added safety is well worth the small added cost.

Nonreturn valves are specialized valves that are found on the main steam outlet closest to the boiler. Most nonreturn valves are double acting, they open automatically when the steam pressure in the boiler overcomes the steam pressure in the steam header, and they close automatically when the steam pressure in the boiler is less than the steam pressure in the steam header. Nonreturn valves function as a check valve, preventing steam pressure from the header entering the boiler. The nonreturn valve has two seats attached to the same stem, the top seat acting to cushion the action of the valve. Such cushioning action is known as using a dashpot. Without the dashpot, the valve would chatter. The handwheel is attached to a screw thread that is not attached to the stem with the two disks. The handwheel can close the two disks on their seat and shut off steam flow from the boiler, but when the handwheel screw thread is raised, the steam pressure must overcome header pressure before the disks will rise.



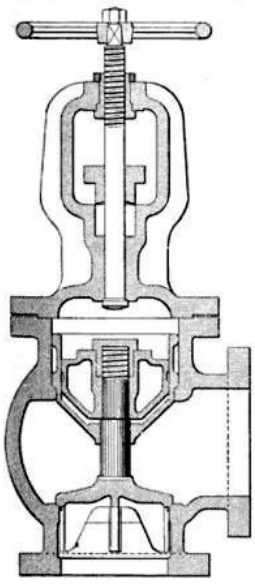
Some nonreturn valves are triple-acting. In addition to raising and lowering in relation to whether the boiler is higher or lower than the header pressure, the triple-acting nonreturn valve will close automatically when the header pressure is 8 lbs. or less than the boiler pressure. This will shut the nonreturn valve if there is a break in the steam header or steam line downstream from the boiler. This is an added safety feature that will keep the boiler from blowing steam out a ruptured steam pipe.

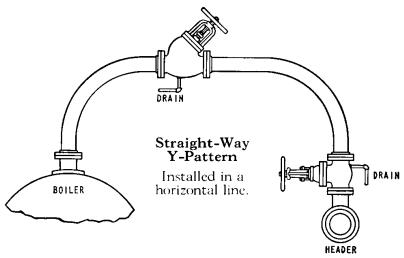
The triple-acting nonreturn valve works as follows: The disk at the bottom of the valve and the disk at the top of the valve are rigidly attached to each other. When the screw thread on the handwheel is raised and the pressure in the boiler is higher than the pressure in the header by a few pounds per square inch, the two disks will open as one to allow steam to flow into the header. Steam flows through the bypass hole drilled through the center of the stem to which both disks are attached. The steam lifts the ball check valve in the stem and allows steam from the boiler on top of the upper disk. The upper disk acts as a dashpot. Small holes in the upper disk allow steam to travel from above the upper disk to the space between the upper disk and the stationary seat just below the upper disk. The steam that is between the upper disk and the stationary seat just below it travels out the small pipe on the side of the nonreturn valve. This steam acts on the bottom of the pilot valve. The outlet from the pilot line is attached to the steam header. As long as the header line and the steam in the boiler are within 8 lbs. of each other, the pilot valve stays closed and the nonreturn valve acts as an ordinary double-acting nonreturn. If the header pressure drops below 8 lbs. for any reason, the pilot valve will lift, releasing steam from the space between the upper disk and the stationary seat just below it. This unbalanced pressure, with the boiler pressure above the upper disk pressing down on it, will close the valve.

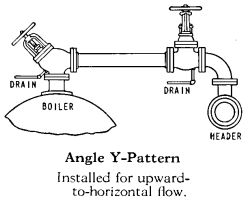


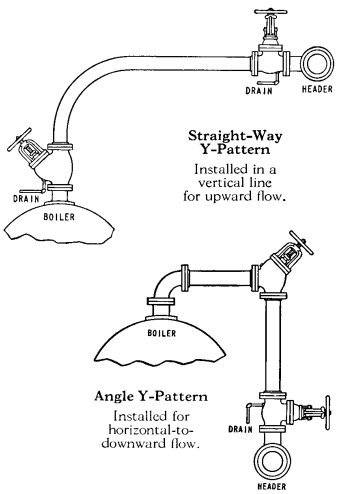
The reason that the lower pressure of the header will not allow the lower disk to rise, is that the upper disk is larger in diameter than the lower disk, creating more force on the upper disk. The pilot valve is weighted with steel shot to hold the valve on its seat until the header pressure is reduced sufficiently.

The test valve on the side of the nonreturn valve is normally closed. All other valves are open. When the test valve is opened, it relieves the pressure in the space between the upper disk and the stationary seat just below it. This should shut the nonreturn valve as described above. The steam pressure on the boiler should rise as the nonreturn valve closes. Shutting the test valve will open the nonreturn valve and restore normal operation.









BOILER TUBES

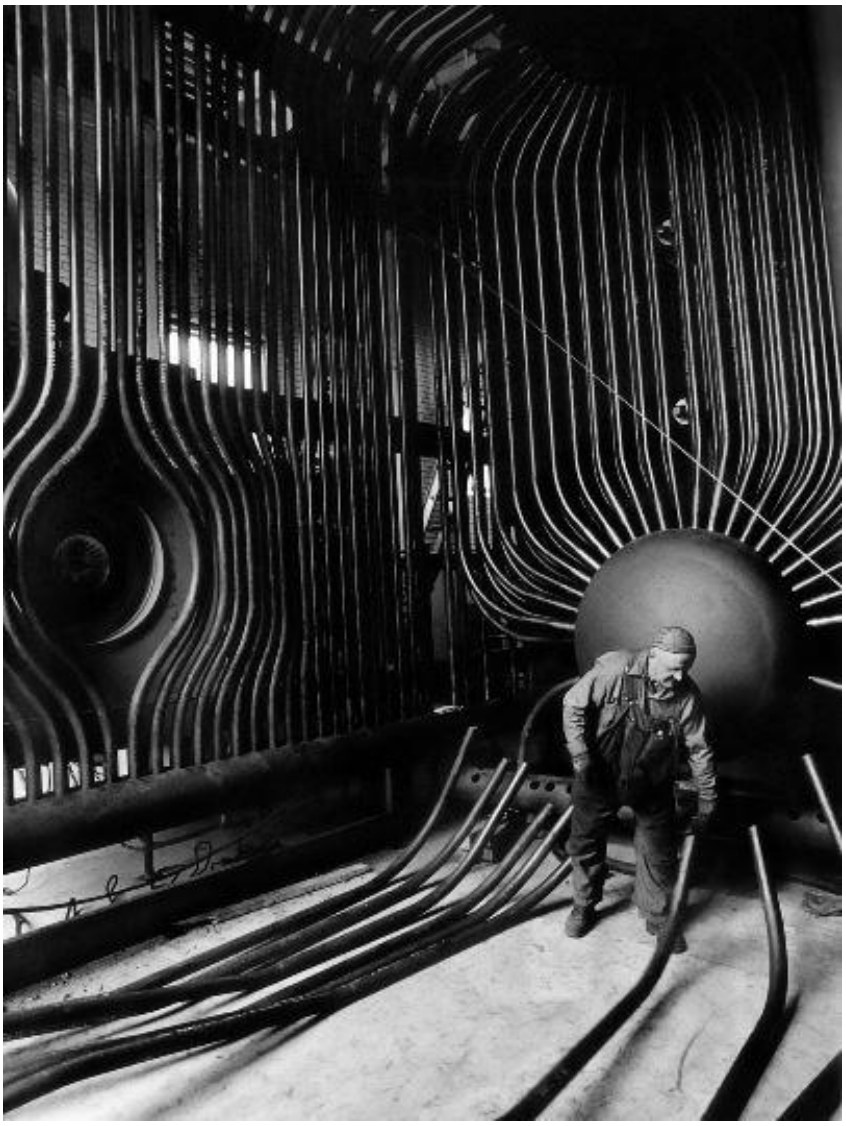
Boiler tubes are made by either the seamless process or the electric resistance welding process. In the seamless process, the hot solid rod of steel is pierced through the center of the rod with a mandrel as the outside of the rod is drawn through rollers to control the outside thickness. In the electric resistance weld method, sheets of steel are folded together to form a tube and the automatic welder welds the edges of the sheets together.

Both types of tube are used for boilers. The seamless tube is favored by some because the thicker walls and lack of a seam are considered advantageous. The resistance welded tubes are more uniform in thickness, lower cost, and easier to roll.

Most boiler tubes are made of low carbon steel when operating temperatures do not exceed 750 to 800 degrees Fahrenheit. Higher temperatures require tubes with a higher carbon content, alloys such as carbon molybdenum, or stainless steel.

Boiler tubes are measured by their outside diameter. The sizes are as follows: ASTM, ASME standards

1 1/4
1 1/2
1 3/4
2
2 1/8
2 1/4
2 1/2
3
3 1/4
3 1/2
4
4 1/4
4 1/2
5
5 1/2



Installing water tubes in a field erected water tube boiler

PIPING

Steel pipe is made by the same processes as tubes. They are made to conform to the American Society for Testing Materials specifications A53-30. Pipe comes in three weights, standard or schedule 40, extra strong or schedule 80, or double extra strong or schedule 160. Pipe is measured by its nominal inside diameter, which means that the hole inside the pipe is supposed to be close the size that the pipe is called. This does not mean much. The outside diameter must remain the same so that fittings of different weights will screw onto pipes of different weights. A schedule 160 double extra strong fitting will screw onto a schedule 40 standard pipe. This means that the inside diameter of the pipe gets smaller as the schedule number of the pipe gets bigger to increase the strength.

The Top wrench should be at the bottom of the tee fitting in order to prevent twisting or crushing the top thread

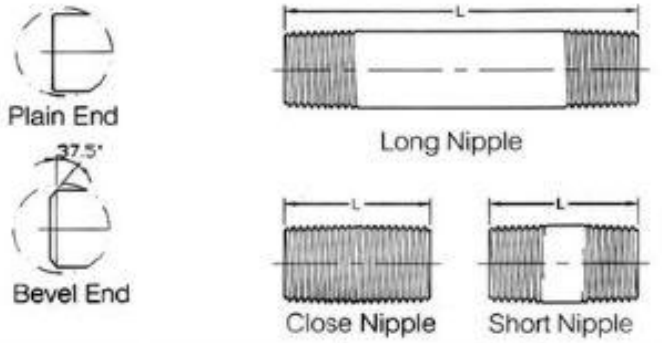
Pipe is threaded on the end so that it can be screwed into various fittings to turn directions, reduce or increase in pipe size, or to tee out so that flow can go in more than one direction. Unions are essential to allow pipe to be screwed together. Without a union, the last piece of pipe could never be screwed into place. Pipe can be threaded with a hand threader or with a threading machine. Pipe is installed using two pipe wrenches, one to turn the pipe and the other is used to hold the fitting in place so that it will not turn. 4 inch is normally the largest threaded pipe.

Pipe sizes are as follows:

1/8
1/4
3/8
1/2
3/4
1
1 1/4
1 1/2
2
2 1/2
3
3 1/2
4

Pipe Nipples Threaded

ASME A773-03



Nom. Pipe Size	L			Plain End Weight (kg/m)			
	Close Nipple	Short Nipple	Long Nipple	Sch40/STD	Sch80/XS	Sch160	XXS
1/8"	3/4	1-1/2	2~12	0.37	0.47		
1/4"	7/8	1-1/2	2~12	0.63	0.80		
3/8"	1	1-1/2	2~12	0.84	1.10		
1/2"	1-1/8	1-1/2	2~12	1.27	1.62	1.95	2.55
3/4"	1-3/8	2	2-1/2~12	1.69	2.20	2.90	3.64
1"	1-1/2	2	2-1/2~12	2.50	3.24	4.24	5.45
1-1/4"	1-5/8	2-1/2	3~12	3.39	4.47	5.61	7.77
1-1/2"	1-3/4	2-1/2	3~12	4.05	5.41	7.25	9.55
2"	2	2-1/2	3~12	5.44	7.48	11.11	13.44
2-1/2"	2-1/2	3	3-1/2~12	8.63	11.41	14.92	20.39
3"	2-5/8	3	3-1/2~12	11.29	15.27	21.35	27.68
3-1/2"	2-3/4	4	4-1/2~12	13.57	18.64		
4"	2-7/8	4	4-1/2~12	16.08	22.32	33.54	41.03
5"	3	4-1/2	5~12	21.77	30.97	49.12	57.43
6"	3-1/8	4-1/2	5~12	28.26	42.56	67.57	79.22

If an old length of steel piping starts to drip at the threads, do not attempt to tighten it. The rust has eaten through the pipe threads and the pipe is about to fail. Turning the pipe with a pipe wrench will snap it off and a deluge will result. **Do not turn a nuisance into a disaster**. If the piping is critical to the plant's operation, schedule a time when it can be taken out of service. Screwed pipe lasts about 10 to 15 years because threading thins the metal and removes any galvanized coating it may have had. Painting the threads with an anti-corrosion paint will increase its life expectancy but all cutting oil must be removed from the surface first.

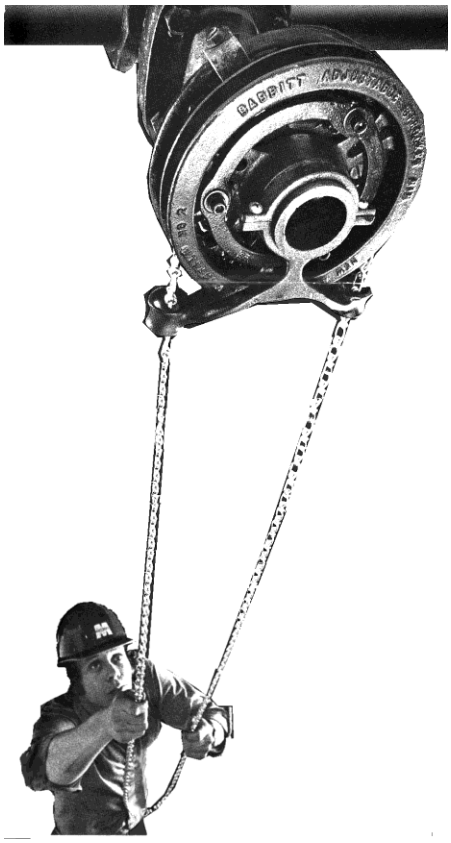
Do not buy Chinese pipe, fittings, or valves. They are clearly inferior products that are difficult to make leak tight.

Boiler rooms use threaded steel pipe only because of its resistance to damage when hit with an object. Plastic will break and copper will dent. When you tighten screwed steel pipe take small bites with the wrench close to but not on the threads. The pipe will tend to oval if you keep putting the tightening pressure on one spot.

Copper pipe is easier to install with an excellent resistance to corrosion.

Never install a valve in a large vertical length of steam piping. Condensate will form on top of the valve and opening the valve will cause a large slug of water to hammer the pipes. Operators have died from this. If you find one in your boiler room, report it and have it moved to a horizontal pipe.

When you install a valve on a horizontal run of steam pipe, mount the valve horizontally so it can be operated from the ground by a chain.

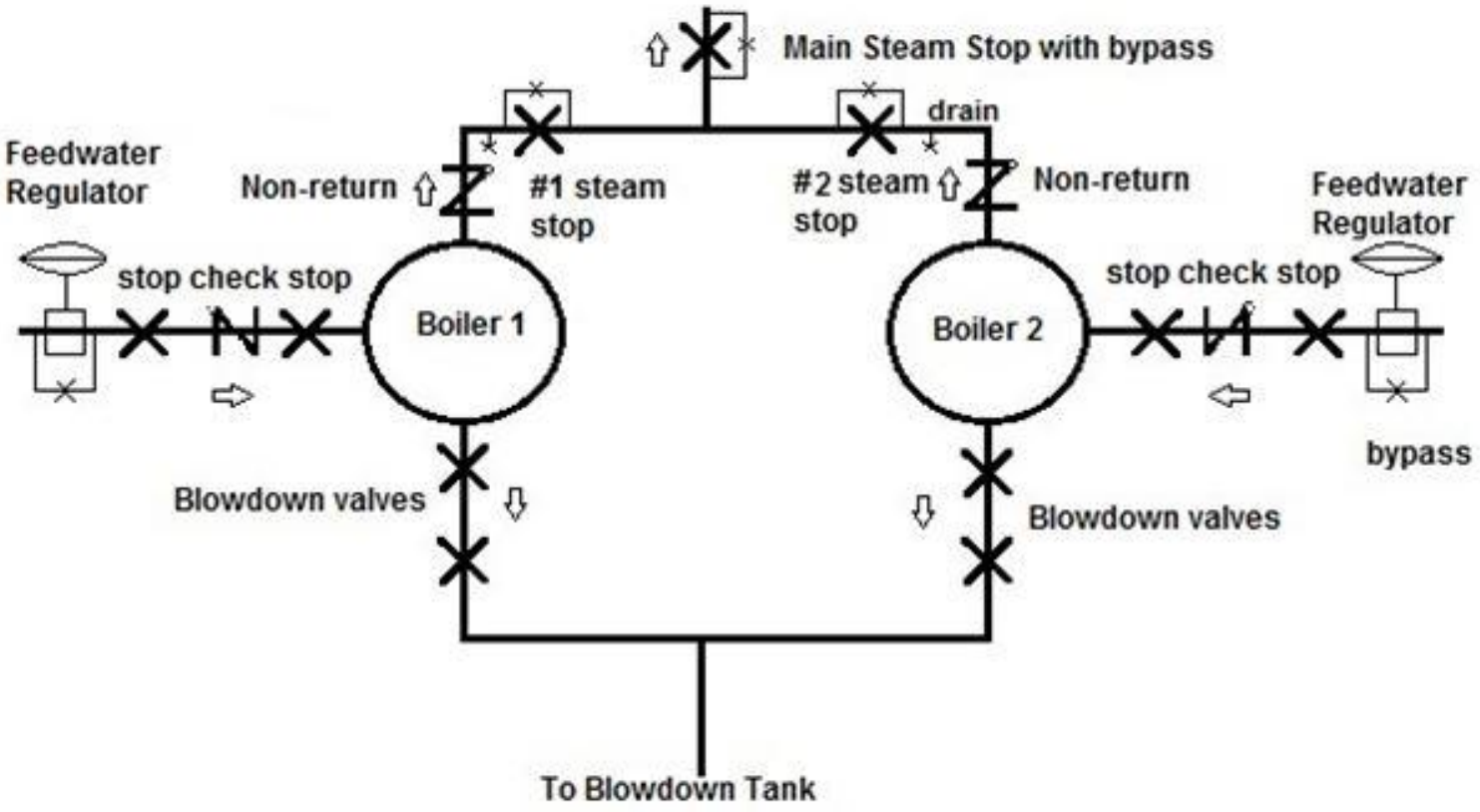


Never install a steam valve with the stem pointing down.

Dual Plate Check valves should be installed with the hinge pin vertical so that if the spring breaks, the reverse flow will still close the valve

Never tighten a bolt or nut that is under pressure unless you want to meet your maker with a wrench in your hand and a sign around your neck that says "I died for my Company."

Don't feel lonely. Your buddy who liked to hit steam valves and pipes with a hammer to "make something happen" will be right there alongside you.



On a High Pressure Boiler Operators examination, you will be handed a sheet of paper on which the Examiner has drawn two circles with lines coming from those circles. He will tell you that this drawing represents two boilers in a battery. You are to draw all the valves necessary to operate the boiler and explain the purpose of each valve.

Starting from the left hand side of the drawing, you have a feedwater regulator with a bypass around it. Next is the stop-check-stop valve combination that is necessary under the Code for any boiler installation feeding water to a boiler. Going from the top of the boiler you have a Non-Return valve and then a Steam Stop Valve for each boiler. There is a drain valve on the header between the Non-Return and the Steam Stop Valve to drain any condensate that may have accumulated. The steam then passes through the Main Steam Stop on the way to the load. If there is a steam line break outside the boiler room, the Main Steam Stop is closed to prevent any further loss of steam. All valves over 8 inches have a bypass around them for warming the line and to make it easier to open the valve.

There will be two blowdown valves coming from the bottom of each boiler, headed for the blowdown tank. You may add other valves but these are the minimum necessary to pass that portion of the exam.

PIPING COLOR CODES

According to ANSI/ASME A13.1, pipe markers should conform to certain requirements. The most recent update to the ANSI/ASME A13.1 code has introduced a new color scheme that specifies which colors to use for pipe labels. The code also specifies standards for the label sizes and placement.

In 2007 the ANSI/ASME A13.1 standard was updated and is now recommended for all new pipe marker applications. For facilities with existing pipe markers, it is recommended that they are updated for consistent identification.

Pipe Contents	Color Scheme
Fire-quenching fluids	White text on red
Toxic and corrosive fluids	Black text on orange
Flammable fluids	Black text on yellow
Combustible fluids	White text on brown
Potable, cooling, boiler feed, and other water	White text on green
Compressed air	White text on blue
User-defined	White text on purple
User-defined	Black text on white
User-defined	White text on grey
User-defined	White text on black

The current version of the ANSI / ASME code uses a pipe labeling standards color code chart with six standard color combinations, and four user-defined combinations, as shown in the table below. The colors are based on the contents of the pipe; in general, the most hazardous feature of the contents should determine the colors used.

Bare Pipes should be painted with the appropriate colors. Insulated pipes should be labeled. Zip ties on either end of the label in addition to the adhesive backing should be used to hold the labels in place. Follow the fluid flow from high pressure to low pressure and place the flow arrows correctly.

Chapter 10 Questions

1. Describe a globe valve.
2. For critical feed service, which way should the water enter the globe valve?
3. Describe a gate valve.
4. Which valve should be used to throttle flow, the globe or the gate valve?
5. Why are small bypass lines placed around larger valves?
6. What are the advantages of a butterfly valve?
7. Can butterfly valves be used to regulate flow?
8. What precautions must be taken when mounting a check valve?
9. Describe a swing check.
10. Describe a lift check.
11. Describe a ball check.
12. Describe a dual plate check valve.
13. What added function will a triple-acting nonreturn valve perform that a double-acting nonreturn valve will not?
14. Why are nonreturn valves necessary?
15. How are seamless boiler tubes made?
16. What are the three weights of pipe?

Chapter 11

BOILER OPERATION

The first thing a Boiler Operator should do upon entering the boiler room at the beginning of a shift is to check the water level in the gauge glass. Use hearing protection once you enter the boiler room. Next, the Boiler Operator should blow down the water column and gauge glass to ensure that the water level in the glass is correct. The water column and gauge glass are always blown down at the beginning of each shift. The Low Water Cut out must be blown down. The Operator must arrive early enough to ask the previous Operator if anything unusual has occurred. Do bottom blows while the other Operator is there to watch the gauge glass.

BLOW DOWN THE WATER COLUMN AND GAUGE GLASS

1. While wearing gloves, open the drain on the water column and blow for about 30 seconds. The whistle on the column should blow while the valve is open. If there is a low water cutoff bypass button, you may press it while opening and closing the valve until the low water cut-off alarm stops sounding. Close the valve.

2. If the water column is at a high location, use the chains attached to the gauge glass valves to operate them. If you do not have them, get them. Close the steam end of the gauge glass and open the drain on the gauge glass. The water will shoot to the top of the glass. Let the drain blow for 30 seconds. This will clear the water end of the gauge glass. Close the drain and open the steam end of the gauge glass.

3. Close the water end of the gauge glass and open the drain on the gauge glass. Allow the steam to blow through the drain for 30 seconds to clear the steam end of the glass. Close the drain and open the water end of the gauge glass. This completes blowing down the water column and gauge glass.

This procedure is very important because if the column or gauge glass became blocked, you no longer know the true water level in the boiler and a disaster is sure to result. Water columns that are high use chains to allow the Operator to operate the gauge glass valves from the floor. Some manufacturers use only one set of chains attached to both the steam and water end of the gauge glass. Buy another set of chains and hook them to each valve individually. If both steam and water valves are opened and closed at the same time, one end can become blocked and the action of blowing down will not open the passage because the steam or water is taking the path of least resistance.

The water should come back in the glass rapidly after blowing down the column and gauge glass. If the water does not come up within 5 seconds, the water connection to the column is becoming clogged and the boiler should be shut down and the obstruction cleared.

A blocked steam connection from the boiler is rare but very dangerous. The water in the gauge glass is will go to the top falsely indicating high water. The try-cocks will also show a false high water level in the boiler. This might cause the Operator to blow down the boiler to try to lower the water level and wind up damaging the boiler due to low water. The only way to determine if this has happened is to shut off the lower connection to the water column (if it has valves on the lines to the column) and open the drain on the column to see if steam will blow through.

Check the trycocks often to ensure the gauge glass is operating properly. They are called TRY cocks for a reason. The top trycock should blow dry steam, the middle trycock a mixture of steam and water, and the bottom trycock water. Due to the decrease in pressure, some water will flash into steam at both the middle and bottom trycocks when there is a normal water level in the boiler, but you will learn the difference with experience.

After you have ensured that the water level is correct, the next thing to do is check the log book to make sure no unusual events have occurred in the boiler room since you were last on shift. The log book is a bound book of clean sheets of paper in which each shift Boiler Operator writes down the events of his shift. If the Operator has opened any valves or made any changes in the operation of the plant, they must be logged so the other Operators are aware of these changes. Not logging changes and not reading the log book are serious offenses which are sure to result in a reprimand. It is important to use a bound book with numbered pages and indelible ink so that no one can alter the log. Some Plants use strips of cloth tied around a valve wheel to alert others if a valve is not in its normal position. Always carry a Maglite and a Leatherman tool in your pocket. You will use them often.

After checking the log book, the Operator thoroughly checks all equipment. There is usually a boiler room log sheet on a clipboard for the Operator to write down all important pressures and temperatures. The Operator should check any readings that are different than normal. Gradual changes in operating conditions can be spotted by the use of the log sheets. One Operator, usually the one on the midnight shift, will log the water, fuel, and electrical consumption for the day. Any 24 hour revolving charts are replaced at midnight. In the morning, the midnight Boiler Operator will call for the weather forecast and place it in the log book.

The Operator will take the boiler water samples and write down the results of the boiler water tests. Adjustments to the continuous blowdown line and determining the amount of chemicals to be added to the boiler are done after taking the tests. Any bottom blows should be done under light load.

The Operator should have specific pieces of equipment assigned for preventative maintenance. The Operator will grease pumps and motors, lubricate linkages on fan dampers, clean burner tips and strainers and do other necessary jobs. A sheet of paper inside a clear plastic sheet protector should be near each piece of equipment. When the Operator does any maintenance on the equipment, it is written on the maintenance sheet and placed back in the sheet protector. These sheets are never replaced when they are completely filled out. The new sheet is added to the sheet protector. This allows the entire maintenance history of each piece of equipment to be readily seen.

It is the Operator's job to keep the assigned equipment clean. Find a dirty boiler room and you will find a place where "everybody" is responsible for keeping it clean. When everybody is responsible, "nobody" will take it upon themselves to do the entire job of cleaning. The boiler room is not the storage dump. If it does not have a specific purpose for the boiler room, it does not belong there.

The Operator should have a desk and chair placed so that the water in the gauge glass can be monitored at all times. Boiler Operators will instinctively learn the rhythm of equipment and the frequency of pitch that the equipment makes. If something goes wrong in the boiler room, the Operator will probably hear it first. Boiler rooms are noisy. Always wear hearing protection. The equipment in the boiler room can still be heard and hearing damage is lessened.

STARTING A NEW JOB

When you are hired as a new Boiler Operator, one of the first things to do is get a large sketchpad and start drawing all the boilers and all the piping and valve locations in the boiler room. Pay special attention to all the water lines and pumps that feed water into the boiler. In an emergency, you need to know all the ways to get water into the boiler. Is there an injector on the side of the boiler as an emergency feed source?

Trace all water lines, steam lines, blowdown lines, fuel lines, chemical feed lines, and any other piping in the boiler room. It will take some time to trace everything but that piping isn't going anywhere and you will have free time to complete the drawings. If you are working at an old plant, there have been upgrades over the years and some piping may have been abandoned. Put flow arrows to show what direction the fluid is going. Remember that pressure flows from high pressure to low. Just because there is an arrow on the pipe pointing in one direction does not mean that it is correct.

Find all the electrical circuit breaker panels in the boiler room. Do they have updated panel directories? Probably not. See if management will provide circuit tracing equipment so that the panels can be updated.

Write down all the nametag data of all the equipment in the boiler room. See if the Operations and Maintenance Manuals are available for each piece of equipment. If they are not there, do an internet search and print them off. If they are not available on line, call or write the manufacturer and ask for them. Why should you do all the legwork? Isn't that somebody else's job? The answer is that it is your job. It is your life you are trying to protect. A boiler room can be a dangerous place. You will have emergency situations arise. **Panic is nothing more than not knowing what to do**. If you have learned everything there is to know about the equipment you were hired to operate and where all the valves and switches are located to control that equipment, you should be able to handle the situation and prevent a disaster. Play the "What If" game in your mind. "What would I do if this happened?" If you do have what you need to be prepared for an emergency, make written requests until you get it.

Get a list of all the vendors and their phone numbers. Are boiler chemicals or salt for the softener running low? Having a good relationship with the vendors can allow for an emergency shipment with billing to follow.

Check the inventories of commonly used spare parts. Make sure you have spare gauge glasses, and new rubber composition washers. Have a gasket cutting kit and the correct gasket material on hand. Lubricating oil should match the manufacturer's specification. Spare piping and valves should be on hand. If your plant has threaded steel pipe you will need a powered pipe threader and "nipple packs" of short nipples for each of the different sizes of pipe. Have pipe dope and Never-seez on hand. Small tubing with fittings for control lines will be needed, along with Teflon tape.

Your toolbox should have all the tools needed to handle most repairs. What are the largest size nuts and bolts in your boiler room? Do you have the sockets and boxed end wrenches that will fit. You don't need the most expensive tools, you need the appropriate tool. Tools that break are dangerous. A professional air gun is essential to break free these large rusted nuts. Sometimes heating with an oxy-acetylene torch is the only way to break them free.

THE PROPER METHOD TO USE A GREASE GUN zerks

The manufacturer's data will give you the right type of grease for each piece of equipment. Make sure you have it on hand in a properly labeled grease gun. The grease required for the hot bearings of a feedwater pump will not be the same as the grease required for the pump motor.

You might think it odd to discuss the proper way to grease a piece of equipment. You just pop the fitting on the grease zerk and pump like mad, right? Wrong.

Grease is a poor substitute for oil. Put an oil reservoir on a motor bearing and make sure it is filled to the proper level and that motor can last 50 years in a clean environment. Management is not about to hire people to check every electrical motor's oil level so grease is substituted. Grease is soap emulsified with oil. When the oil heats up and runs out, you are left with a hard crud that doesn't lubricate well.

To properly grease a piece of equipment, lay down a rag and pump the grease gun. A solid slug of grease should run out for the length of the stroke of the grease gun. Many times a thin stream will come out, and sometimes nothing. Loosen the threads at the top of the gun and start pumping to drive air out. No resistance against the pumping action of the lever means no grease is going into the bearing.

Remove the bottom plug on the bottom of the bearing housing and use a small screwdriver to dig the crud out of the hole. Leave the plug out. Take an ink pen or similar small object to press in on the ball of the zerk fitting to make sure it will depress. Place the grease gun fitting on the zerk and **pump 3 times.** That is it. Do not try to get grease flowing out the bottom hole. Leave the plug out for 2 hours and then replace the plug.

TRUE STORY #1. A Chief Engineer of the boiler room was going to show a new Boiler Operator how to grease a 30 horsepower pump. He took out the bottom plug without cleaning the hole and pumped a whole 14 ounces of grease into the zerk. No grease came out the hole He said "Hmm that's funny". He took another grease gun and pumped another 14 ounces of grease into the zerk. When no grease came out he took a pneumatic greaser like they use at an automotive garage and started pumping. After about one minute the motor made a weird sound as it gave up the ghost and came to a stop. The rubber grease seal was the path of least resistance and rather than pushing the crud out the bottom hole, all that grease went into the motor until the motor could not rotate any more. The motor was removed and cleaned at the motor shop.

TRUE STORY #2. At another Plant a brand new Induced draft fan motor was installed and the men installing the fan motor came down from the top of the boiler platform with four empty 14 ounce tubes of grease. "Where did you put that grease?", they were asked. "Into the motor." they replied. When the Chief Engineer was informed he said that it was too late to do anything about it. When the Mechanical Engineer at the plant heard about it, the Chief was relieved of his position. The fan motor was removed, cleaned, and reinstalled properly.

Overgreasing a bearing until grease comes out the bottom hole can lead to bearing overheating even if the grease is getting into the bearings. Bearings should be 1/2 full of grease.

When the Boiler Operator is doing his rounds, there are things to check even if they are not on the logsheet.

Check the stack temperature. It should be no more than 100 degrees above the saturated steam temperature. If a boiler is running at 150 psi, the saturated steam temperature is 365 degrees and the stack temperature should not be over 465 degrees. For every 40 degrees of stack temperature above 465 degrees, there is a 1% loss in boiler efficiency. A rise in stack temperature could be due to sooted tubes, scaled water side surfaces, or missing or cracked baffles.

The Deaerating heater should be 5 psi at 227 degrees Fahrenheit. If the temperature is lower than this, there could be mechanical problems that need to be checked out when the plant is down. Scaled trays in the tray type or plugged nozzles in the spray type.

TRUE STORY #3. One day the Chief Engineer drives up to the plant and says "Every day as I drive up I see steam leaking out the top of the Deaerating Heater". "We are wasting a lot of money." He had the pipefitters replace the gate valve at the top. When they handed him the old gate valve, he said "That's funny. It has a perfectly round 1/8 inch hole in the center of the gate valve disk. It looks almost like it was a drilled hole." Not long after that the temperature of the Deaerating Heater started dropping dramatically and colder and colder water was getting to the boiler. "Maybe that hole was there for a reason", said the Chief. He had them replace the new gate valve with the old one and the temperature went back to normal.

Daltons Law of partial pressures states that every gas in a vessel acts as if it was in the vessel by itself. The air that was now trapped in the Deaerating Heater kept the steam from entering and heating the water. Once the vent was reopened, the air could escape and steam could get back in to heat the feedwater.

As a Boiler Operator there will come a day when someone from Management will ask you to do something incredibly stupid. As long as you are sure it will not risk life and limb, you smile and say "I'd be happy to do that for you. Just write it down on a piece of paper in your handwriting, date and sign it." You will see Management stop as if a 12 foot deep hole with sharpened bamboo spikes at the bottom just opened up in front of them. They are just smart enough to realize you are setting a trap for them. You will never see that piece of paper and you will not be bothered by them as often.

Once you have a license, do not do anything to jeopardize that license. You can always get another job if you have the license.

REPLACING A ROUND GAUGE GLASS

It is not unusual for a round gauge glass to break in normal service. The caustic boiler water will eat away at the inside of the glass until the pressure is great enough to burst the glass, sounding like a shotgun blast. Close the water end first. Steam rises. A boiler with a water softener for pretreatment is more likely to have a higher pH. This is the reason for using a gauge glass shield around the glass to prevent the flying glass, steam, and water from injuring boiler room personnel. The necessary supplies must be on hand to replace the glass quickly and with a minimum of problems. It is better to have the correct length of gauge glass bought and kept in stock. If not, glasses that are longer than necessary are cut to size. Special cutters are used to etch the glass and then snap off the excess. Do this ahead of time so you have spares available. Also needed are new rubber washers, brass washers, and a small packing hook to remove the old rubber washers. A good pair of leather gloves and a face shield must be worn to protect against broken glass and hot metal. The boiler water level must be checked with the try-cocks while the glass is being changed.

The procedure is as follows:

1. Close the steam and water end of the glass and open the drain from the glass.

2. Loosen the packing nuts on the steam and water end of the glass. If the glass is in one piece, push the glass up into the steam end, tilt the glass out at the bottom and remove the glass and packing nuts. If the glass is broken, remove the two packing nuts. Carefully remove any broken pieces of glass in the water end.

3. If you have to cut a new glass, use the space between the top and bottom gauge glass valves as a guide. Notice that the bottom seat is about 1/4 inch below the lip of the threads that the packing gland screws onto. Notice also that the top seat has a space about 3/4 of an inch between it and the lip of the threads on the top valve. A glass cut 1/2 inch longer than the distance between the lips of the threads will allow the glass to clear the threads and when the glass is on its bottom seat, about 1/4 inch of the glass will be above the top lip. If the glass does not go up into the top when it is on its bottom seat, it will not work.

4. Place the packing nuts on either end of the new glass, followed by the brass washers, followed by the new rubber washers. Remember that you must have the brass washers against the packing nuts to allow the packing nuts to turn freely while tightening. If not, the rubber will bind against the glass when turning the packing nuts and may cause the new glass to break. It also helps keep the red stripe on the glass at the back while tightening.

5. Tilt the glass into the steam end and then seat the glass on the bottom. While holding the glass, tighten the packing nut on the bottom. After it is tight, tighten the nut on the top.

6. The drain on the gauge glass should still be open. Slowly crack the steam valve on the glass and let the steam blow slowly through the glass to warm it. After the glass is warm (about 30 seconds) open the water end of the glass and close the drain. This completes the job.

To clean a dirty gauge glass, remove the glass from the water column and use a small piece of soft cloth tied around a cotton string. Dip the cloth in household ammonia for a cleaner. Feed the string through the glass and then pull the cloth through. Never use a wire to pull the cloth or anything abrasive to clean the glass as the glass is sure to break when it is put back in service.

FLAT GLASS REPLACEMENT

The flat gauge glass is a big improvement over the round glass because it is stronger and the prismatic effect of the ridges inside the glass cause the water to look black making it much easier to see the water level. The round glass will get a dirty ring around the normal water level if it is not kept clean. This can fool an Operator into thinking the correct water level is showing when it is not. The disadvantage of the flat glass is that it is more expensive, and due to the construction, the water will fall out of sight in the glass about two inches higher than the round glass due to the steel stem and the steel bottom of the front plate.

The flat gauge glass will rarely break. What will happen is that the gasket around the glass will fail and steam will start to blow around the glass. Never try to tighten the nuts on the glass to get the steam to stop blowing. It is dangerous and 99.9% of the time it will not work anyway. Be sure to wear a good pair of leather gloves and a face shield during the replacement. It is best practice to have a spare flat glass assembly ready to go.

The replacement procedure is as follows:

1. Shut the top and bottom valves to the glass and drain the gauge glass.

2. Loosen the top and bottom packing nuts, lift the gauge glass up into the top, tilt it out at the bottom, and remove the entire gauge glass assembly. Take the entire assembly to the work area next to the boiler. Check the try cocks often during the replacement procedure if a spare gage glass assembly is not available. This will take some time to do correctly.

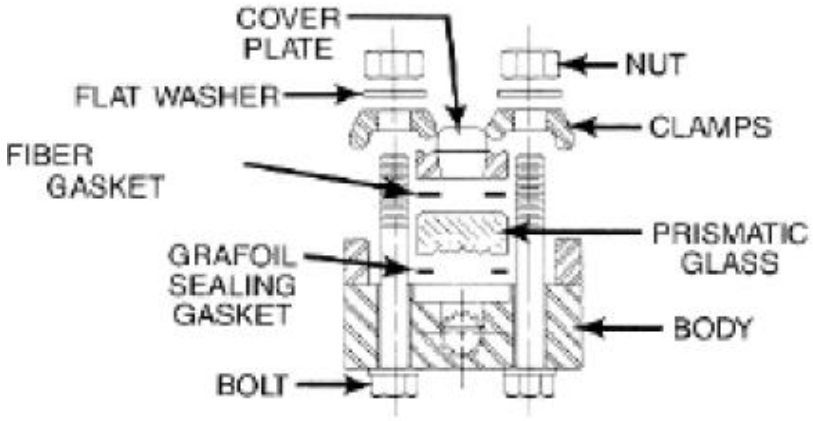
3. Remove all the bolts or nuts that are holding the front plate of the gauge glass down.

4. Remove the front plate, noting the layers of gasket and any mica sheets between the front plate and the glass. Make a small sketch so that you do not forget the layers.

5. Throw away the old glass. Be careful with it as the inside ridges can become razor sharp due to the caustic action of the boiler water.

6. Carefully scrape the old gasket material from the body and the front plate of the gauge glass. If you put any scratches in the metal it will not seat properly. If you leave any pieces of the old gasket it will not seat properly. Take your time and do a good job.

7. Using new gaskets and mica sheets (if used), reassemble the gauge glass in the opposite order that it came apart. Use copper high temperature anti-seize compound sparingly on the gasket and you will not have to scrape the gasket the next time. Use nitrile or rubber gloves. Use your thumb and index finger to spread a thin film of anti-seize around the gasket. Be sure and use a new gauge glass.



PRISMATIC TYPE

8. Tighten the bolts or nuts starting at the center on each side and work outward in a crisscross pattern to both ends. Tighten them just past finger tight on the first round and then go back over the same pattern and tighten them again and then a 3rd time, torqued to 40 ft. lb.

9. Put the packing nuts back on the gauge glass and use new brass washers and rubber gaskets on the stems. Push the glass up into the top of the steam end of the gauge glass and swing the bottom end over and down into the water end of the gauge glass. Tighten the bottom packing nut first and then tighten the top packing nut.

10. The drain on the gauge glass should still be open. Open the top valve on the gauge glass slowly and let the steam blow through the glass for 30 seconds to warm the glass. Open the water valve and then close the drain.

GAUGE GLASS PROBLEMS

There are 4 possible scenarios of the water level in the gauge glass not matching the water level at the trycocks.

1. Normal water in glass, high water at trycocks and the whistle is blowing.
2. Normal water in glass, low water at trycocks and the whistle is blowing.
3. High water in glass, normal water level at trycocks
4. Low or no water in glass, normal water level at trycocks

Number 1 scenario: normal water in glass, high water at trycocks

Causes:
1. Gauge glass valves shut
2. Lower gauge glass connection clogged shut

Number 2 scenario: normal water in glass, low water at trycocks

Causes:
1. Gauge glass valves shut
2. Lower gauge glass connection clogged shut

Number 3 scenario: high water in glass, normal water level at trycocks

Causes:
1. Top gauge glass valve shut (fast rise in level)
2. Lower gauge glass valve shut (slow rise in level due to condensation)

Number 4 scenario: low water in glass, normal water level at trycocks

Causes:
1. Gauge glass drain open
2. Gauge glass valves shut and packing leaking at bottom nut of gauge glass

If you ever find the gauge glass full of water and the whistle or alarm is not working, and try-cocks showing a high water level in the boiler, check the following to find out the problem with the whistle:

1. The whistle may be broken.
2. The top float may have come loose.

If the gauge glass is showing a normal water level and the trycocks are showing a normal level and the whistle is blowing, check the following:

1. The bottom float could have filled with water and sank.
2. The needle valve on the float may have stuck open after blowing down the column.

BLOWING DOWN THE BOILER

Never leave a boiler unattended after you have opened the blowdown valves. If the phone rings, the safety valve pops, or anything else happens that might distract you, close the blowdown valve before you leave. Blow down the boiler under no load or low load. Always open any valve under pressure slowly.

If a boiler has a quick and a slow-opening valve, use the following procedure:

1. Keep your eye on the gauge glass when blowing down. Use two people or set a mirror on a stand so that you can watch the water level while blowing down.

2. Open the quick-opening valve first by turning or pulling the handle.

3. Open the slow-opening valve and you will be blowing down the boiler. Blow down for 10 seconds at a time. If you are trying to reduce the solids and sludge in the boiler, several short blows are better than one long blow.

4. When you are done blowing down the boiler, close the slow-opening valve.

5. Close the quick-opening valve.

6. Open the slow-opening valve to drain the water trapped between the two valves.

7. Close the slow-opening valve.

If the boiler has two slow-opening valves, use the following procedure:

1. Open the valve farthest from the boiler first.

2. Blow down the boiler using the valve closest to the boiler by opening it.

3. Be sure to use short 10 second blows.

4. When done blowing down the boiler, close the valve closest to the boiler first.

5. The final step is to close slow-opening valve farthest from the boiler.

You will definitely be asked this procedure on an exam. You would be surprised at the number of Operators who do not know the correct procedure for using two slow opening valves. The reason for this process is so you do not trap water between the two valves and damage them.

With a quick and slow valve, this is not a problem, but remember to drain the water between them .

BOILING OUT A NEW BOILER

1. Fill the new boiler to the normal water level. You must measure the quantity of water going into the boiler by using some type of water meter, or use the manufacturers data (if available) on the amount of water in the boiler at 1/2 sightglass. You can also see how long it takes the feed line or a water hose to fill a 55 gallon drum and then time how long it takes to fill the boiler drum. Then divide 55 by the time to find the number of gallons per minute that the line is supplying. Multiply the time it takes to fill the boiler by the gallons per minute and you have the total gallons of water in the boiler. Multiply the gallons by 8.33 and you have the number of lbs. of water in the boiler

Example: A water line takes 5 minutes to fill a 55 gallon drum. The same line fills the boiler to 1/2 sightglass in 1 hour and 36 minutes. How many pounds of water are in the boiler?

A. Time it takes to fill 55 gallon drum: 55 gallons divided by 5 minutes = 11 gallons per minute.

B. 1 hour X 60 minutes per hour = 60 minutes + 36 minutes = 96 minutes

C. 96 minutes X 11 gallons per minute = 1056 gallons total in the boiler.

D. 1056 gallons X 8.33 pounds per gallon = 8796.5 pounds of water in the boiler.

2. Measure out into separate buckets 2 pounds of each of the following chemicals for each 1000 pounds of water in the boiler: Caustic Soda, Soda Ash, and Tri-Sodium Phosphate.

If we use the example described above, then we would use 17.6 lbs. (8796.5 / 1000 X 2) of each of the three chemicals.

3. If the manhole opens on the top, open it and pour the chemicals carefully into the drum. Wear rubber gloves, protective clothing, and a face shield when handling any boiler chemicals.

4. If the boiler's manhole is at or below the water level, use a funnel to pour the chemicals into the vent on top of the boiler.

5. Close up the boiler and run on low fire until the boiler is at 1/3 normal operating pressure. Then shut off the burner and let the pressure drop to 1/4 normal operating pressure before restarting the burner. For example, if the normal operating pressure is 100 psi, the boiler would be fired until the pressure was 33 psi, and then shut off until it reached 25 psi, when it would be restarted to repeat the cycle. Once every eight hours blow down the boiler with two 10 second bottom blows. Fill the boiler back to the normal operating level after each blowdown with hot make-up water. Continue this procedure for three days. At the end of three days let the boiler cool until the boiler has no pressure and will not burn you if you touch the metal but it is still warm. Vent the boiler. Open the blowdown line and start draining the boiler. When the water level is below the manhole, open the manhole and start washing down the inside of the boiler with a hot water hose. It is very important that you do not let any foreign matter dry on the internal boiler surface.

6. After the boiling out is completed, you must replace the gauge glass with a new one as the caustic cleaning agent will etch the glass and cause premature failure.

PREPARING THE BOILER FOR INSPECTION

Usually several boilers are connected together to a common steam header so that a boiler can be made ready for inspection while the others are still on the line providing steam for the plant. In order to allow the Boiler Inspector to examine the idle boiler in complete safety, the following procedure must be adhered to. Remember that the Inspector does not want to see a dirty boiler that has not been properly prepared for inspection. He has the power to prevent the operation of the boiler until it meets his approval, and management will not be pleased to learn that your lack of preparation has caused problems with either the State or the insurance company that is insuring this boiler. Call and set a date for the Boiler Inspector to arrive at your facility and inspect the boiler. Before that date arrives:

1. Raise the boiler pressure until all the safety valves pop. Note the pressure on the steam gage at the point each valve pops. If any valve does not pop or if a valve leaks, tag the valve for removal and repair while the boiler is down. Do not allow the boiler pressure to exceed 6% above the maximum allowable working pressure.

2. Use the sootblowers to clean the fire side of the boiler just before you shut down the boiler.

3. Shut off the boiler and lock out any electrical disconnects that are connected to the boiler that you are preparing for inspection, or pull the fuses. If you have a "remote kill switch" which is an emergency electrical shut-off near the outside door for that particular boiler, now would be a good time to test it.

4. Wait until the pressure is zero, vent the boiler and let it cool enough so that the steel is not hot enough to burn you. Make sure that the pressure has actually dropped to zero and that the vent is not plugged.

5. Chain and lock all blowdown valves on the other operating boilers so that no one can blow down another boiler that is on the line. The hot water and steam will back up into the idle boiler and scald you while you are flushing out the idle boiler.

6. Close, chain, and lock all steam outlets and fuel and water inlets to the idle boiler. Tag with "DANGER Do Not Open" tags.

7. Before you enter the boiler, make sure that it is cool. Use low voltage lighting with ground fault protection to prevent electrocution while inside the boiler.

8. While the boiler is still warm, start draining the boiler through the blowdown line. As soon as the water level is below the manhole cover, open the manhole and start washing the inside of the boiler as the water is draining. Follow safety procedures when opening the manhole cover. Loosen the nuts holding the manhole cover down about 1/2 way off and rap the manhole cover with the wooden handle end of a large hammer. This will prevent injury if a vacuum has formed in the boiler. Washing the boiler while it is still warm keeps most of the solids from drying onto the boiler plate and will make cleaning easier. As the water level gets below any hand holes, take them out and continue washing until all the solids have been flushed into the blowdown tank.

9. Open the drains on the water column, the low water cut-out and the feedwater regulator.

10. If you have not been following a good chemical water treatment program, you will have to clean the water side of the boiler with different types of mechanical cleaners until the tubes are clean. Water tube boilers use various types of cutters, scrapers, or brushes to clean the inside of water tubes. The water sides of fire tube boilers are more difficult to clean because you cannot get to the outside of the tubes that are in the tube bundle. If the deposits are hard scale, they can sometimes be removed by using a device that fits inside the fire side of the tube and attempts to rap the deposits off the outside of the tube. If that does not work, you may have to call in a qualified company to acid clean the boiler. Acid cleaning is something a Boiler Operator should not attempt.

11. Remove all plugs from the crosses of the water column and clean the lines.

12. Open the low water cutout so that the inspector can examine the float and chamber. Clean it.

13. Close, chain, lock, and tag the blowdown lines from the boiler that you are cleaning and then unchain the other boilers' blowdown valves. The blowdown valves run into a common pipe that goes to the blowdown tank. If you do not follow this procedure, hot steam and water would back up into the boiler you have just cleaned and scald anyone inside the boiler or standing near the open boiler.

14. Clean the fire side of the boiler. On a fire tube boiler this means opening the doors to gain access to the tubes and using a flue brush/vacuum combination. There are several manufacturers that make good units that will prevent soot from flying around the boiler room. On externally fired fire tube or water tube boilers with furnaces of sufficient size, crawl in through a furnace door and sweep and vacuum the outside of the tubes. Wear disposable coveralls, tape around your gloves and shoes and wear a tight fitting face mask with a respirator. Carbon dust and ash can be hazardous to breathe. Check for loose or missing bricks in the furnace setting so that they can be replaced. Check for cracks in the furnace wall. Check for corrosion where tubes pass through refractory. Sight across tubes that are in rows to see if any are bent or bulged.

15. Wire brush around any seams or stay bolt ends.

16. Make note of anything that you feel is unusual as you are cleaning the boiler in order to tell the Inspector. Examples are broken staybolts or any bulging of boiler metal. Remember that the Inspector is trying to insure your safety, so do not hide anything from him. You can always get another job in this trade, but you cannot get another you.

17. Check the refractory for damage and make any repairs necessary.

Boiler Inspector inside boiler drum by feedwater pipe

18. Have all water treatment logs and operating logs available.

19. Only after all this is completed does the Inspector come to inspect the boiler.

PLACING THE BOILER BACK IN OPERATION WITH OTHER BOILERS ON THE LINE

1. Check to make sure that no rags or tools were left in the boiler.

2. Put plugs back into the crosses and reassemble the low water cutout. It is good practice to wire brush the old pipe compound from the threads before using new compound.

3. Wire brush all hand holes and man holes and put new gaskets on them. Coat gaskets with high temperature lubricant so they will come off easily when the boiler is taken down for inspection next year. Clean the mating surfaces inside the boiler and replace all hand holes and manholes.

4. If the gauge glass has not been replaced recently, replace it.

5. Unchain all valves.

6. Make sure that the vent is closed and that the boiler has no openings to the atmosphere. Make sure all steam outlets are closed. Make sure that the blowdown valves, water column drains, low water cutout drains, and feedwater regulator drains are closed, and the water column and gauge glass valves are open.

7. Start filling the boiler with the bypass around the feedwater regulator until the pressure on the boiler is at normal operating pressure (in the case of a boiler that operates under 60 psi) or until the water level is about two inches in the glass. Then shut the bypass feedwater valve. The pressure on the boiler should be about 45 psi. Go around the boiler and check for water leaks from any hand hole gaskets, manhole gaskets or threaded connections. On manholes above the water level, spray a soap bubble solution around the seams to check for air leaks. If there is a leak, vent the boiler, drain it below the level of the leak and fix the source of the leak. Filling the boiler this way will save the problems associated with firing the boiler to raise pressure and then discovering a leak that requires cooling and draining.

8. If no leaks are found, vent the pressure from the boiler and leave the vent open. If you have a shot feeder, add the chemicals to the boiler through the shot feeder. If you do not have a shot feeder, open the manhole and pour in the boiler chemicals using rubber gloves and a face shield. Open the feedwater valves to the boiler.

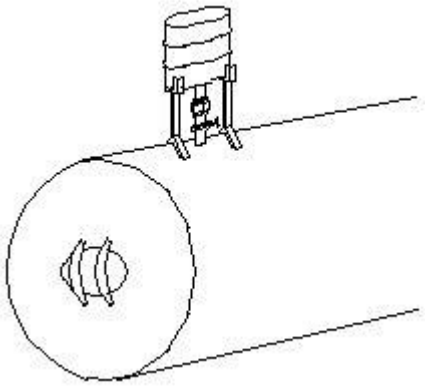
9. Start the boiler on low fire. When steam is coming steadily out of the vent, close the vent. Crack the bypass line to warm the steam line between the non-return valve and the main steam stop. Open the drain on the line between the non-return valve and the main steam stop to drain the condensate. When there is 75% of full load pressure on the boiler, test the safety valve by using the lifting lever with a rope. Make sure the drain plug and adjustment plugs are tight on the safety valve.

10. When the pressure in the boiler is close to the pressure in the steam line, open the main steam valve on the header and close the bypass valve. Close the drain on the line between the main steam stop and the non-return valve when dry steam is blowing. Open the stem on the non-return valve and as the boiler pressure exceeds the pressure in the main steam line, the disk on the non-return valve will lift and the boiler will float on the line.

11. If you have a steam flow meter you will see the pen start to move as the non-return valve is lifting and the boiler starts producing steam for the plant. The boiler controls on the other boilers should start to operate the linkage on the other boilers' firing apparatus to close the fuel and dampers on their burners as the steam from the oncoming boiler is entering the steam line. Open the feedwater regulator once the boiler is steaming to feed the boiler but keep an eye on the water level.

WET AND DRY BOILER LAY UP

When the boiler is going to be shut down for a short time, the boiler is usually laid up wet. Add enough caustic soda to bring the amount of chemical in solution to 450 parts per million to increase alkalinity from a Ph of 8 to 11 and reduce the possibility of corrosion from acid attack. Add enough sodium sulfite (which is an oxygen scavenger) to bring the amount of chemical in solution to 250 parts per million, to protect the boiler from oxygen pitting.



A small barrel can be placed on the outlet of the vent to ensure that the boiler is completely full of water. The barrel has legs to support its weight on the boiler, and a union for quick attachment and removal.

Another method is to use bottles of compressed nitrogen to put a blanket of nitrogen gas over the water. Nitrogen is an inert gas that will not harm boiler steel. Nitrogen is heavier than air and can drive the air out the vent. After the air is driven out, and the vent is closed, a nitrogen pressure of 5 psi is left on the boiler to prevent air from getting back into the boiler. When it is time to put the boiler back in operation, the nitrogen from the tank is shut off and the nitrogen is vented from the boiler during startup.

Dry Lay up of boiler

To lay up a boiler for a longer period of time, six months or longer, use the dry method.

1. Shut down and drain the boiler following all safety procedures of "Preparing the Boiler for Inspection".
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2. Wash out the waterside of the boiler following the draining procedure of "Preparing the Boiler for Inspection".

3. Remove all ashes from furnace. If the ashes have gotten into the plastic refractory where the tubes go into the header at the bottom, it is advisable to remove the refractory to get the ashes out. The ashes contain sulfur that can severely corrode the tube ends and can require tube replacement. It is easier to replace refractory than tubes.

4. Detach and blank off all piping going into or leaving the boiler. This eliminates the possibility of water leaking into the boiler. If the main steam stop and the non-return valve are shut tightly, locked with chains, and tagged out of service with the drain (not steam trap) locked open in between the two valves, this should suffice for the steam line.

5. Place unslaked lime in shallow pans in the steam drums and mud drums. Use 30 pounds of unslaked lime for each 1000 square feet of heating surface of the boiler.

6. Close up the boiler, using new manhole and handhole gaskets, and then put a Nitrogen blanket of 5 psi on the boiler. Put 2 floodlights and small fan inside the furnace to prevent condensation

ACCUMULATION TEST

The accumulation test ensures that the safety valves are large enough to handle all steam that can be generated by the boiler when fired at its maximum rate without going over 6% of the maximum allowable working pressure on the boiler or 6% above the pressure setting of the highest set safety valve. The test procedure is as follows:

1. Close all steam outlet valves.

2. Increase pressure limiting control on automatic combustion controls so they will not shut off the burners when the normal operating pressure is exceeded.

3. Set water level just below 1/2 glass.

4. Put burners in maximum high fire if the fuel is oil or gas. On coal fired boilers, set stokers to maximum firing rate.

5. When the popping pressure of each safety valve setting is reached, the safety valves should pop and start relieving so that the pressure on the boiler does not exceed 6% of the maximum allowable working pressure stamped on the valve tag of the highest set valve or 6% above the maximum allowable working pressure on the boiler, whichever is lower.

6. If the valves cannot relieve the pressure, the test is stopped immediately and the pressure is relieved by shutting off the boiler and opening the main steam valve. More safety valves are required.

7. Accumulation tests are not done on boilers with superheaters, reheaters, or on high temperature hot water boilers.

HYDROSTATIC TEST

The hydrostatic test ensures that the boiler is safe to operate by putting 1 and 1/2 times the normal operating pressure on the boiler using water pressure. The procedure is as follows:

1. Shut down the boiler following all safety procedures, and Lock Out Tag Out all Electrical to the Boiler.

2. Clean the fire side thoroughly so you can spot any leaks.

3. Remove brickwork and insulation from rivets, seams, and joints.

4. Remove the safety valves and replace with blank flanges.

5. Remove the normal steam gauge and replace with a calibrated steam gauge.

6. Remove the high and low water whistle and plug the opening. Filling the boiler will cause water to leak out of the opening. Temporally close off any instrument lines attached to the boiler.

7. Vent the boiler and drain it completely. Follow safety procedures.

8. Remove all handhole and manhole gaskets and install new gaskets. Replace all handhole and manhole covers.

9. Close drains, fill boiler with warm water with a temperature of no less than 70 degrees F. so that condensation will not form on the outside of the boiler and give a false indication of a leak.

10. Run a hose from the vent to the sewer until the water runs freely with no air bubbles.

11. Shut off the water, remove the hose and attach a special hand pump to the vent and pump the water pressure to 1 and 1/2 times the maximum allowable working pressure.

12. Check tube ends, seams, manholes and handholes, flanges, and blowdown connections for leaks. The Authorized Inspector will monitor the test and tell you how long to keep it pressurized.

13. If there are no leaks at these places but the pressure drops off, Some valve connected to the boiler is leaking water past its seat. The pressure will have to be relieved and the boiler drained, and all valves blanked off until the test is completed and the pressure on the boiler holds steady.

14. The Authorized Inspector will determine if the boiler has passed the test.

EMERGENCY OPERATION

Low Water

If you find the water level below the gauge glass, shut off the fuel. Shut off the air supply. If the feedwater pump has stopped supplying water to the boiler, DO NOT TRY TO RESTART IT. If the feedwater pump is running and supplying water, do not shut it off. If there are other boilers supplying steam, the non-return valve should shut when the steam pressure on the boiler with low water has dropped below line pressure. If it is the only boiler supplying steam, shut the main steam stop slowly as you watch the steam gauge. You want to shut the main steam stop without raising the pressure on the boiler to keep as much water in the boiler as possible without popping the safety valves. Don't lift the lever on the safety valve to relieve the pressure. Don't do anything else. Wait for the boiler to cool. If the feedwater pump was running and the water gets to 1/2 glass with the main steam stop closed, shut off the feedwater inlet valve to avoid overfilling the boiler. Call the Authorized Inspector. Do not run the boiler until the Inspector has declared the boiler to be safe to operate. If someone wants you to fire up the boiler to resume production, it is time to seek employment elsewhere. If you have a license you can always get another job. If you lose your license by running an unsafe boiler, or worse, lose your life for your company, you will not have to worry about another job.

Shutting off the fuel on an oil or gas fired boiler is as easy as shutting off the switch. If for some reason that does not work, shut off the fuel valves leading to the boiler. Shutting off the fuel to a coal fired boiler is more difficult. Wet down ashes outside of the boiler with water and throw them on top of the fire. Do not spray the live coals with water. It can create explosive methane gas. If you can pull the burning coal out on the brick floor with a hoe then do so. Close the ashpit doors and open the firing doors. On a spreader, chain grate, or travelling grate stoker, shut off the fuel feed and put the grate on maximum speed to run the coal into the ash pit. Some smaller traveling grate and chain grate stokers are on wheels that could be rolled out from the boiler.

Tube Rupture

If a tube ruptures, shut off the fuel feed. Continue feeding the boiler with water until the boiler cools down unless the other boilers on the line start losing water level due to the inability of the pump to keep up. If you have another feedwater pump, start it to keep the pressure in the feedwater lines until the boiler cools. Watch the level in the condensate tank and the deaerating tank. If the make-up water supply cannot keep up with the rate at which you are losing water through the ruptured tube, you will have to shut off the feedwater supply to the boiler with the ruptured tube. After the boiler has cooled call the Inspector.

High Water

If the high water whistle is blowing, check the water level with the trycocks. If you do have high water, check that the load has not suddenly increased. If not, start blowing down the boiler. If the boiler is running a steam engine or turbine, shut them down to prevent water slugging and destruction of the equipment. Open the drains completely in the steam line before the engine or turbine to be sure all water is drained from the lines.

Foaming and Priming

Foaming is a chemical reaction from impurities in the water that keeps the bubbles from breaking free of the water surface. The bubbles gather together into larger bubbles until the disengaging surface is covered and the water level starts to roll as the steam bubbles from below rise to the surface. If this continues, the water will splash out into the steam line. The mechanical action of the water splashing out is known as priming and the water that is splashed out is known as carryover. In order to control foaming and priming, close the steam outlet valve to determine the true water level. Then reduce the firing rate and open the surface or continuous blowdown valve wide until the foaming ceases.

Priming can also be caused by firing a boiler more heavily to produce more steam than it was designed to handle. The steam bubbles are so numerous that they push the water level up until the water level rolls like waves in the boiler. Lowering the firing rate is only the solution to this type of priming.

TRUE STORY #4

At Eastland Mall, an enclosed shopping mall in Harper Woods Michigan, the boilers suddenly started foaming so badly they could not see the water level no matter what they tried. They sent the maintenance mechanics out to trace the condensate lines to see if they could discover the problem. A plumber had just installed a new commercial dishwasher in a restaurant and decided the condensate line was the nearest drain line available so all the detergent went straight into the boiler.

BOILER REPAIRS

All repairs in this section are to be performed by qualified companies that specialize in boiler repair. The Boiler Operator should not attempt these repairs. The material is presented so that the Operator can become familiar with the methods used and be able to answer the Boiler Examiners questions about these repairs.

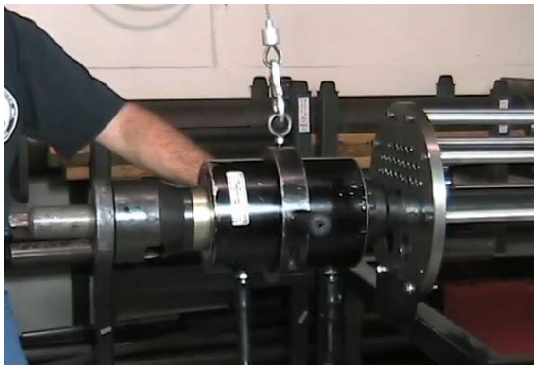
Cracks

Cracks in boiler steel are repaired by welding. The Authorized Inspector must make the determination whether the crack can be repaired or whether the boiler is to be condemned. Welding is the process of using an electrical arc to melt the boiler plate and adding a filler metal of similar properties to the piece to be welded. The crack has a "V" cut into it with a grinder to allow the welder to add metal with the filler rod. The first pass down the "V" is usually done with a TIG welder. The Tungsten Inert Gas welder uses a needle of tungsten to ignite the arc. Argon gas goes through a hollow cylinder that surrounds the needle. The argon blows air away from the weld and protects the weld from the contamination of the atmosphere. A filler rod is fed into the welding zone with one hand while the arc is maintained with the other. If the weld requires much filler material, further passes are made with a "stick" welder. The flux coated welding rod ignites the arc and deposits the metal from the rod at the same time. The flux is consumed in welding and produces protective gasses around the weld. The manufacturer of the boiler should be consulted prior to repair for any special procedures to be followed. An ASME approved welder must do the repair.

The area around the weld is preheated from 150 degrees to 400 degrees Fahrenheit before welding. The welder's bead will create a mound above the surface of the boiler plate. The weld area is stress relieved by postheating to 1100 to 1600 degrees Fahrenheit with special electric blankets then allowing the weld to cool in the air. The weld is ground even with the surface. The weld can be X-rayed to insure that no holes or slag inclusions are in the weld.

Manual Tube Removal and Replacement

On straight fire tube boilers, Use a pneumatic rapping scale remover to try to get the scale cleaned from the outside of the tube. If one tube toward the middle of the tube sheet is to be replaced, use a chisel to knock the bead loose around the tube and then start collapsing the end of the tube inward to break the grip of the rolled section of the tube in the tube sheet. Go to the other end of the boiler and do the same to the other end of the tube. Using a short piece of pipe just smaller than the tube hole and a large hammer, knock the tube toward the front of the boiler. When enough of the tube is sticking out the front try to pull the tube out. If the tube will not come easily, drill a 1/2" hole through both sides of the old tube, at least 6" back from the end of the tube, and put a 1/2" steel rod through both holes. Attach a ratcheting cable puller known as a come-along to both sides of the rod, attach the other end of the come-along to a structural member of the building, and pull the tube out. Be careful that the rod does not pull through the tube, relieving the tension and sending the cable of the come-along flying. This method pulls the tube out of the hole rather than trying to push it out by attaching a long threaded rod to the end of the tube, or by trying to beat the tube out the entire length with a pipe.



Courtesy Elliot Tube Tugger

Hydraulic Tube removers are used today to remove tubes. Some have threads that grip the tubes and then a hydraulic ram pulls them from the tubesheet.

If all the tubes are to be replaced, an acetylene torch is used to cut the tubes out in pieces small enough to be removed from the manhole. Leave an inch of the tube protruding on the inside of the sheet. Adequate ventilation is required in the boiler during the cutting operation. Tube ends are removed by collapsing them inward as described in the previous paragraph. The tube sheet is cleaned and all tube holes inspected for damage. The new tubes are placed in the tube sheets, making sure that the tubes have the same amount sticking out of each end. A tubing cutter can be used to even all tube ends. Tubes are rolled using a pneumatic roller. Beads can be formed using a hammer and a hand beading tool or by using the pneumatic powered beading tool. There are tools that will roll, flare, and bead in one operation

Elliot Tube Cutter

REMOVING AND REPLACING BAD WATER TUBES

Put a heavy piece of sheet metal behind the damaged tube to protect the other tubes

Using a pneumatic cutting chisel laying on the mud drum, completely cut across the bad tube and pull it outward from the tube bank.

Drive the stub inward until it drops into the mud drum and remove it from the mud drum.

Go into the steam drum and cut 2 notches into the bell of the tube to be removed without touching the tube sheet

Run the gouge so that it curls a groove without cutting into the tube sheet, the cut is 1/2 the thickness of the tube.

Use the chisel to curl the tube inward without touching the tube sheet

Remove the bad tube.

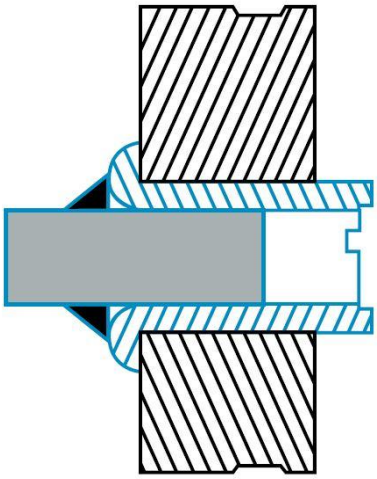
Replace the bad tubes with new tubes.

PLUGGING BOILER TUBES

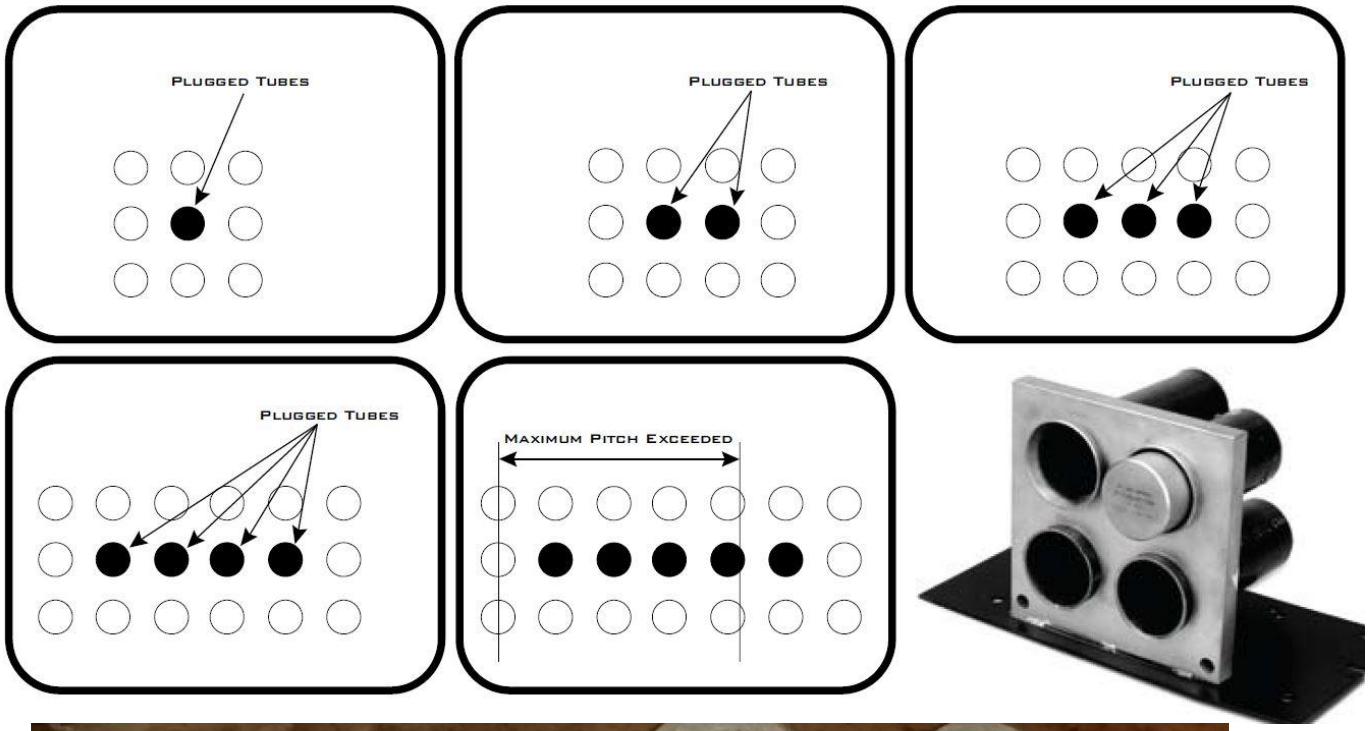
The American Society of Mechanical Engineers is working on rules for plugging leaking boiler tubes. As of now, it is up to the State Boiler Board of Boiler Rules and the Authorized Inspectors. A plug is supposed to be a temporary measure until the boiler can be taken down and the tube replaced. Some owners and management want to extend the time so they do not have the expense of replacing tubes. Whether the tube is mechanically held in place where it may shoot out like a shotgun slug or seal welded is up to the inspector.

Plugged Tube Seal Welded

Boiler Tube Plugs



The amount of tube plugging is becoming excessive and will have to be addressed on a national level.



Undocumented Tube Plugs in the mud drum

The Hartford Steam Boiler Insurance Company issued an Executive Summary to be careful when plugging tubes. "Extensive scale build-up in the insured's boiler had caused several tubes to leak. A repair company found a probe could not be pushed through some the tubes and recommended plugging the offending tubes. This was done at the upper and lower drums. However, water was trapped between the plugs and the scale build-up. The scale must have been completely solid, because when the boiler was fired, the plugged tubes ruptured. The steam release damaged the rear wall of the boiler. Precautions must be taken to assure no water remains trapped between the plugs or between the plugs and internal deposits. One method would be to drill one or more holes in the plugged tubes to vent any trapped water. Normally, plugged tubes are leaking, and the leak provides the necessary vent. In this case it did not. Ultimately, the plugged tubes should be replaced as part of the normal maintenance on your boiler."

Chapter 11 Questions

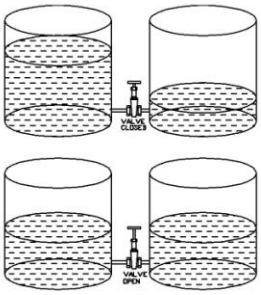
1. What is the first thing the Operator should do upon entering the boiler room?
2. What is the next thing to do upon entering the boiler room.
3. Why is the log book important?
4. How do you replace a round gauge glass?
5. How do you replace a flat gauge glass?
6. The gauge glass and the try cocks show a high water level in the boiler and the whistle is not blowing. What could be wrong?
7. How do you blow down a boiler with a quick and a slow opening valve?
8. How do you blow down a boiler with two slow opening valves?
9. How do you boil out a new boiler?
10. How do you prepare a boiler for inspection?
11. How do you put the boiler back on line after inspection?
12. Explain the wet lay up of a boiler.
13. Explain the dry lay up procedure.
14. Explain the accumulation test.
15. Explain the hydrostatic test.
16. Who can weld on a boiler?

Tig Welding Boiler Tube ends

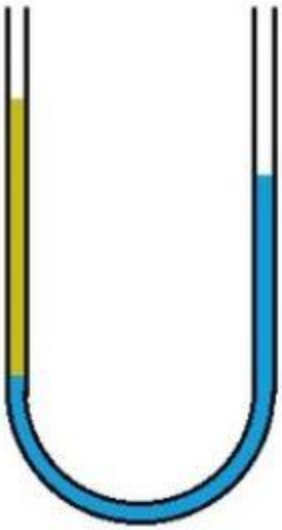
Chapter 12

PUMPS

WHY WE NEED PUMPS



Water seeks its own level. Look at the illustration. When the valve is closed between the two tanks of water they can stay at different heights. When you open the valve, the water from the higher column runs into the lower column until they equalize. This principle works everywhere that the density of the water is the same. The Pacific Ocean is 8 inches higher than the Atlantic because the Atlantic is saltier and more dense than the Pacific.



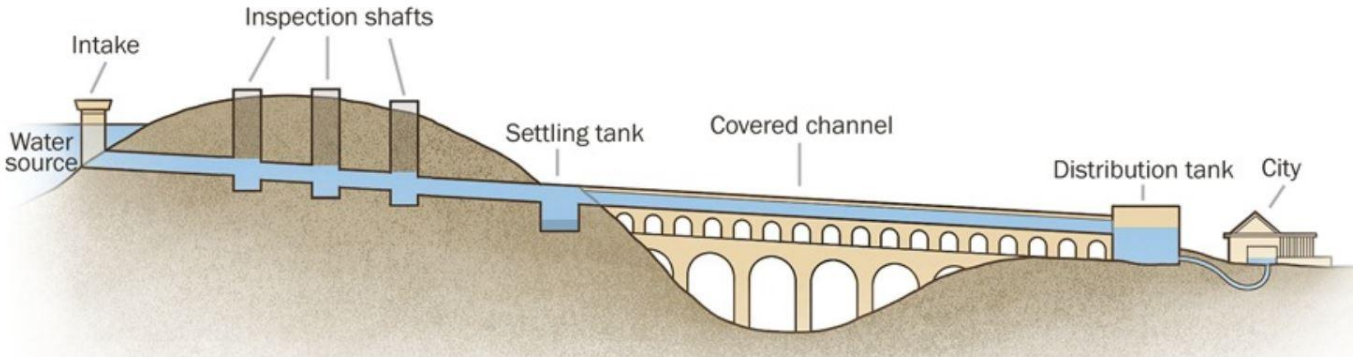
To demonstrate it, let's look at a U-tube having two different fluids that don't mix (e.g. oil and water). If the fluid on the left is lighter (lower density) than the one on the right, its level will also be higher: Similarly, as the water of the Atlantic is more salty (and denser) than the water of the Pacific, the level of the Pacific water is slightly higher to maintain the same "communicating vessel" water level between the two oceans. That is why there are locks on the Panama Canal between the two Oceans.

Water flows downhill. It keeps flowing downhill until it reaches the ocean, where it has found its own level, or until it forms a lake on impermeable rock in the mountains like Crater Lake in Oregon or Lake of the Clouds in Michigan. Water will soak into permeable soil and form underground aquifers and rivers until it find impermeable layers of rock it cannot get through. Otherwise, water heads to the Ocean. A rather rare exception can be seen in the Jordan River, for which the base level is the Dead Sea, 1300 feet below sea level and 1000 feet deep.

Once water gets to where it no longer flows downhill by gravity, you need a way to get it up where you can use it. You need some type of pump in order to do this. Most homes without a municipal water supply have some type of pump to get it to flow into their house. Even if the water flows by gravity from a city water tower, it needed a pump to get it up there. This chapter will discuss the types of pumps you may find in the powerhouse. Though there are many different styles, they all have the purpose of transporting a liquid to where it is needed.

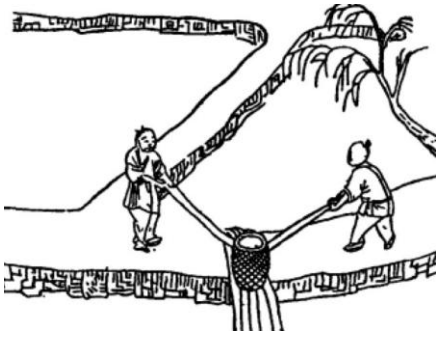
Pumps cannot "suck" water. They create a lower pressure than atmospheric and the water is carried to the inlet by atmospheric pressure pushing on it, just like drinking out of a glass with a straw.

ANCIENT WAYS OF CONVEYING WATER



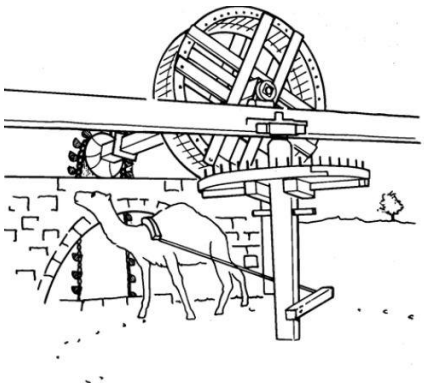
In ancient Roman times, 312 B.C. they started building aqueducts to bring mountain water to cities using gravity rather than pumps. This works as long as you have a source of supply higher than its intended use. Imperial Rome's longest aqueduct was fifty-seven miles in length; the Catskill Aqueduct that feeds New York City is ninety-two miles in length.

Once the water is below where you need it you have to have some means of raising the water.



Two men and a wicker basket

Two men and Archimedes Screw



Camel running a bucket line

None of these early efforts were particularly effective. As the Industrial Revolution got going in the 1800's, and boilers could supply steam with high enough pressure. Steam pumps were used to start supplying water to cities and factories.

Pumps are used in the boiler room for feeding condensate and make-up to the boiler, for fuel oil supply, chemical injection, and for other purposes depending upon the individual plant.

In the case of boiler feed pumps, they raise the pressure of the feedwater high enough to supply the boiler with the boiler at 6% above the maximum allowable working pressure. The pump must also have the capacity in gallons per minute to meet the requirements of the boiler.

When the boiler has over 500 square feet of heating surface, the boiler should have two methods of supplying the boiler with feedwater. This could be two pumps, one of which should be steam powered and the other electrically driven. Another combination would be one pump and one injector. The recommended suggestion is to have all three available. A steam turbine driving the feedwater pump with the exhaust steam used for heating is economical to use in the winter. In the summer when there is no need for the exhaust steam, the electric pump can be used. The injector is always available for emergency boiler feed. Boilers can be fed in an emergency with city water pressure if they are not operated over 15 psi.

There are certain numbers that you have to learn in order to answer questions on the boiler examinations about pumps. These numbers relate to the characteristics of water, its weight, volume and the pressure that it has due to height.

1. 12 inches equal one foot.

2. One square foot equals 12 inches (length) times 12 inches (width) or 144 square inches

3. One cubic foot equals 12 inches (length) times 12 inches (width) times 12 inches (height) or 1728 cubic inches

4. One cubic foot of water weighs 62.5 pounds

5. One gallon of water weighs 8.33 pounds

6. A cubic foot of water contains 7.5 gallons (62.5 divided by 8.33)

7. A column of water one foot high exerts a pressure of .433 pounds per square inch at the bottom.

8. A column of water 2.31 feet high exerts a pressure of one pound per square inch at the bottom.

9. A pound is abbreviated lb. and is short for Libra or the scales used for weighing in the old days.

10. A foot lb. is the force required to move one lb. one foot.

11. One horsepower is the amount of work that it takes to move 33,000 lbs one foot in one minute. Power has the concept of the amount of work (ft.lbs.) that can be done in a certain amount of time (minutes).

12. The Atmosphere exerts a pressure of 14.7 psi. on the Earth at sea level. Gauge pressure takes that fact into account from its starting point so that zero psi on the gauge is equal to 14.7 psi absolute. Gauge pressure less than atmospheric pressure is measured in inches of mercury, also called inches of vacuum.

13. The circumference or distance around a circle is found by multiplying the diameter of the circle in inches by 3.14 (pi).

14. The area of a circle is found by multiplying the square of the radius of a circle in inches by 3.14 (radius X radius X 3.14). Many engineering texts use diameter X diameter X .7854 which will equal the same result.

15. The volume of a cylinder is found by multiplying the area of a circle by the length of the cylinder. (radius X radius X 3.14 X the length of the cylinder in inches).

16. The quantity of the water pumped varies directly with the speed.

17. The pressure that a pump develops varies as the square of the speed.

18. The power required varies as the cube of the speed.

There are many varieties of pumps used in powerplant work. The most popular types are classified as follows:

1. Centrifugal Pumps

A. Volute casing type
B. Double Volute Casing
C. Stationary diffuser type
D. Turbine type
E. Propeller type

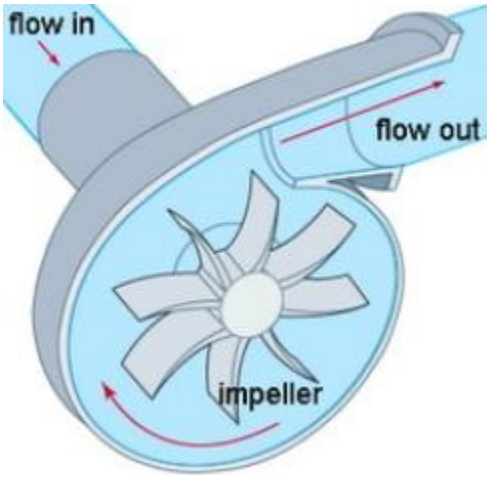
2. Reciprocating Pumps

A. Simplex
B. Duplex
C. Power pumps

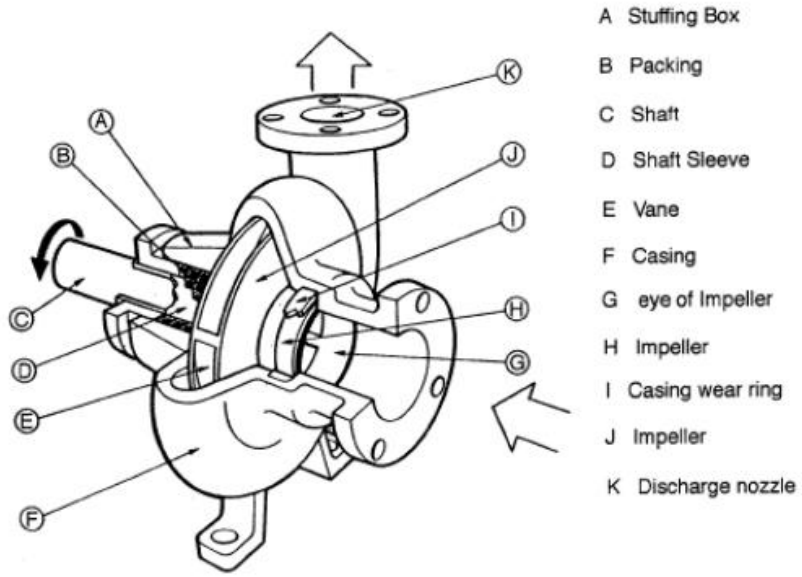
3. Rotary Pumps

A. Gear or Spur-Gear
B. Herringbone-gear
C. Internal-gear
D. Single-screw
E. Twin-screw
F. Three-screw
G. Swinging-vane
H. Sliding-vane
I. Two-lobe
J. Three-lobe
K. Diaphragm Pump

CENTRIFUGAL PUMPS



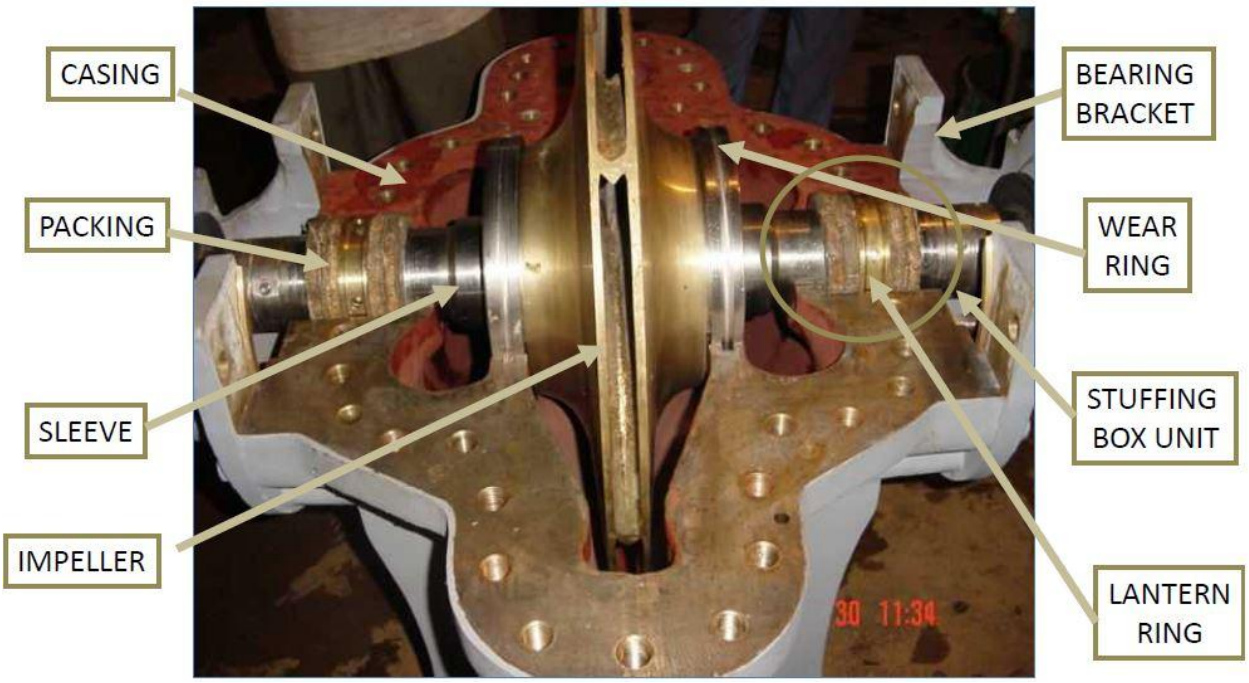
A centrifugal pump consists of a curved impeller rotating at high speed that flings the water from the center or eye of the impeller to the casing at high velocity. In the case of the volute type centrifugal pump, the water loses velocity as it travels around an ever-widening path until it reaches the discharge nozzle. At that point the high velocity has decreased as the pressure has increased. The stationary diffuser type is very similar to the volute casing type except that it has an added ring around the impeller to help direct the flow of water. If the pressure needed is greater than one impeller can supply, the water is sent from the discharge of one impeller into the eye of another impeller and so on until the desired pressure is reached.



Important points to remember about centrifugal pumps are :

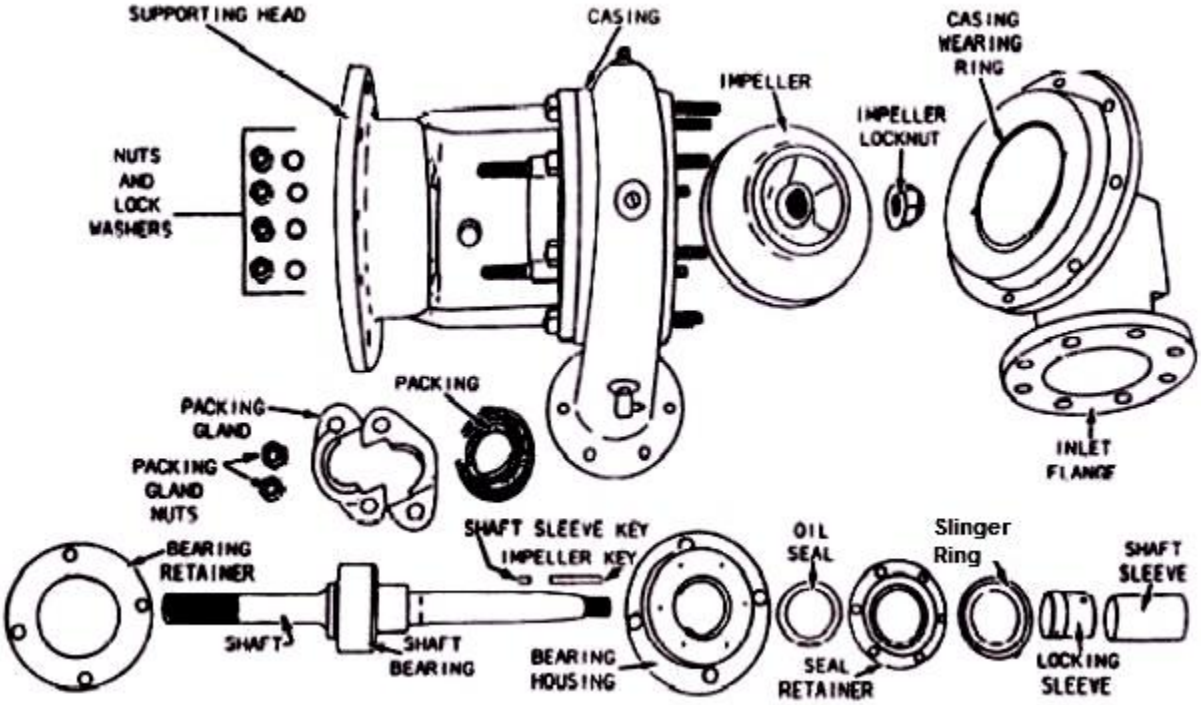
1. The centrifugal pump is considered to have only one rotating part. Actually a centrifugal pump can have oiling rings or ball bearings that also rotate but for the purpose of the license examinations the correct answer is that the rotor with its attached impeller is the only rotating part.

MAJOR COMPONENTS OF A SPLIT CASE PUMP



2. Wearing rings are used around the impeller inlet to keep clearances small to increase efficiency and to allow replacement of the ring rather than the casing or impeller.

3. Wearing rings can be made from cast iron, steel, monel or bronze. Usually the wearing ring on the impeller is of a different material than the wearing ring in the casing to prevent galling or the tendency of similar materials to drag against one another.



4. Centrifugal pumps are not self-priming. If the casing is not full of water, the pump will not draw water into it just by starting the pump. Some method must be provided to ensure that the casing is full of water before starting. These methods include:

a: Having the source of supply above the pump so that water will flow by gravity into the pump suction

b: Having a foot valve which is a type of check valve in the suction line to prevent water from draining out of the pump once it has been primed.

c: If the discharge line is higher than the pump and a discharge check valve has been installed in the discharge line, a bypass line from the upstream side of the discharge check valve piped to the suction side of the pump can be used.

d: If you can get the inside of the pump casing at less than atmospheric pressure, liquid from the suction side will be drawn into the pump as long as the water is not lower than 22 feet below the pump. These methods include vacuum pumps, ejectors, and eductors.

e: You can run a hose from the city water line to the vent on top of the pump and fill the casing with water. Make sure you have a backflow preventer on the hose connection to prevent the liquid from the pump backing up into the city water supply.

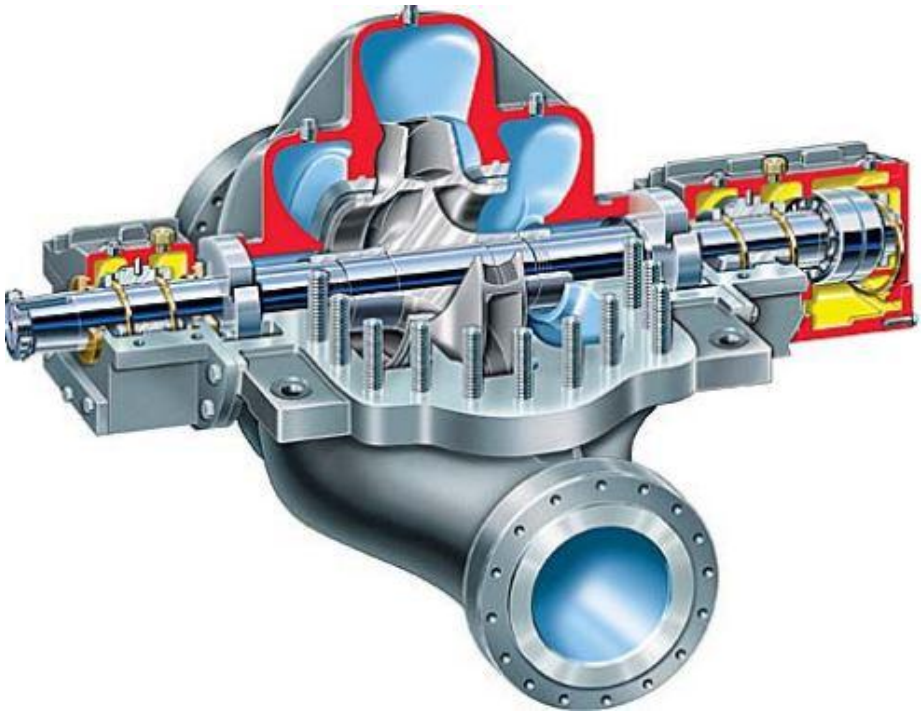
5. Increasing the temperature of the liquid being pumped decreases the head or pressure and the capacity of the pump. Water over 130 degrees F. should be supplied by gravity from an overhead source. This is why the open feedwater heater is always located above the boiler feed pump.

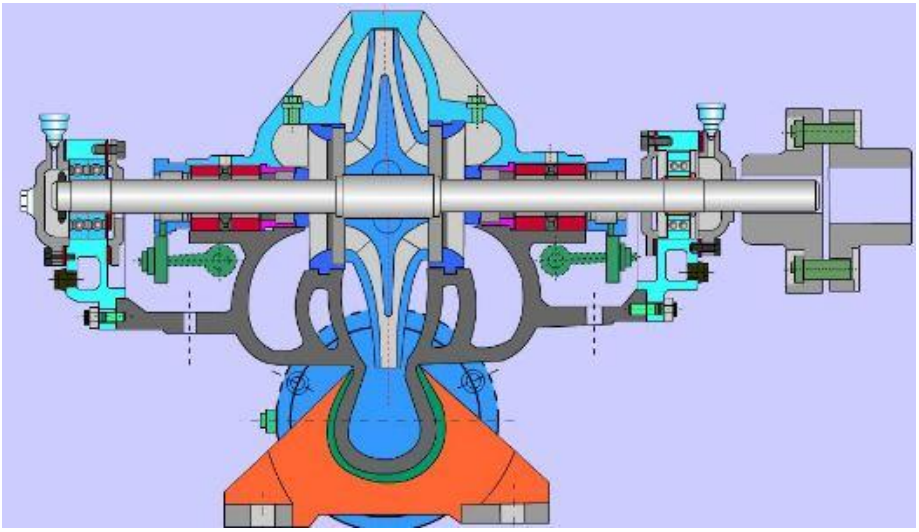
6. The centrifugal pump should be started with the suction valve open and the discharge valve closed to decrease the horsepower required to start the pump. After the pump has started you should open the discharge valve. Output from the pump is controlled by throttling the discharge valve, not the suction valve. Note that the centrifugal pump is the only pump that you do this with. All the other pumps discussed are positive displacement pumps and would be damaged if you tried to start them with the discharge valve closed.

7. The centrifugal pump has a lower efficiency than a reciprocating pump of the same capacity.

8. Centrifugal pumps are subject to cavitation if the suction lift is too high, the water is too hot, or if the head of water above the pump is not high enough. Cavitation is the implosion of air bubbles at the impeller that create noise and erode the impeller.

DOUBLE VOLUTE CASING PUMP





The double volute design is actually two single volute designs where the inlet liquid splits to go into the back-to-back impellers.

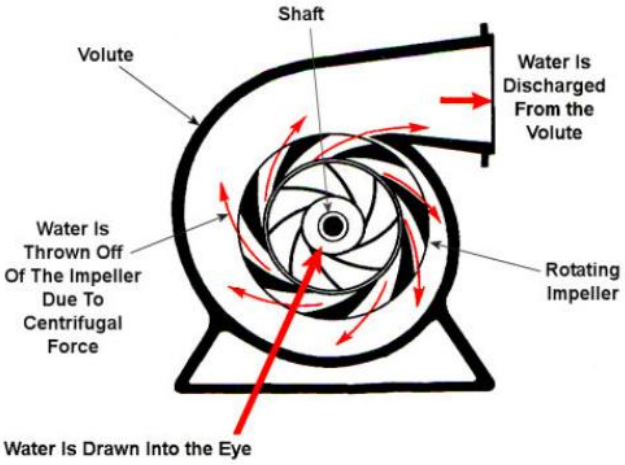
Double volute pumps were created to eliminate most of the axial thrust caused by single volute type

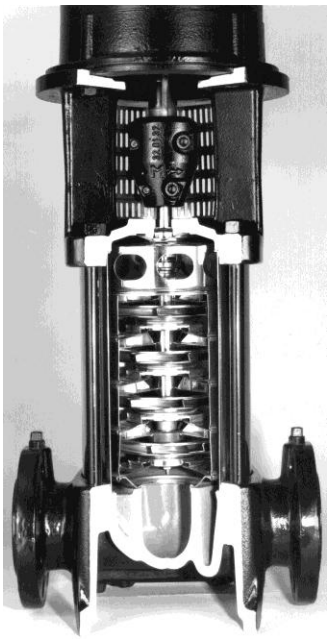
Double volute pumps should never be specified for flow rates less than 400 gallons per minute.

Double volute pumps are specified when large volumes of liquid are required.

Double volute pumps can only handle clean fluids without solids.

STATIONARY DIFFUSER PUMPS

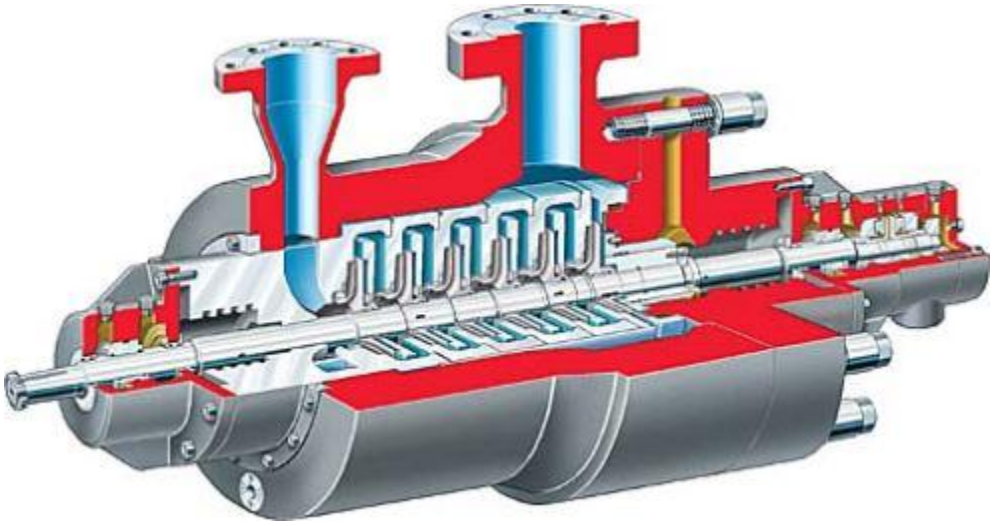

Shaft
Volute
Water Is Discharged From the Volute
Water Is Thrown Off Of The Impeller Due To Centrifugal Force
Rotating Impeller
Water Is Drawn Into the Eye



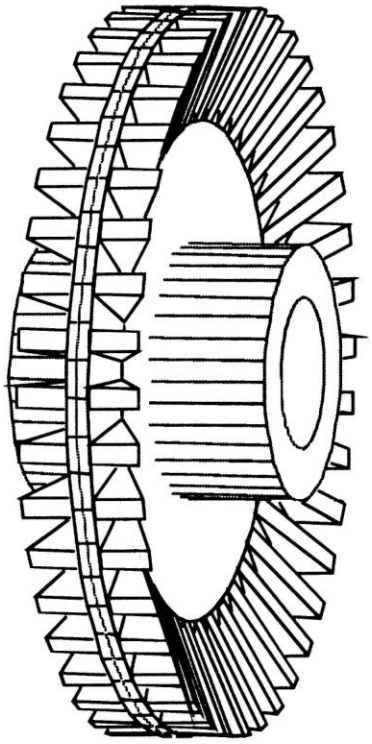
Vertical Stationary Diffuser Pump courtesy Gould Pumps

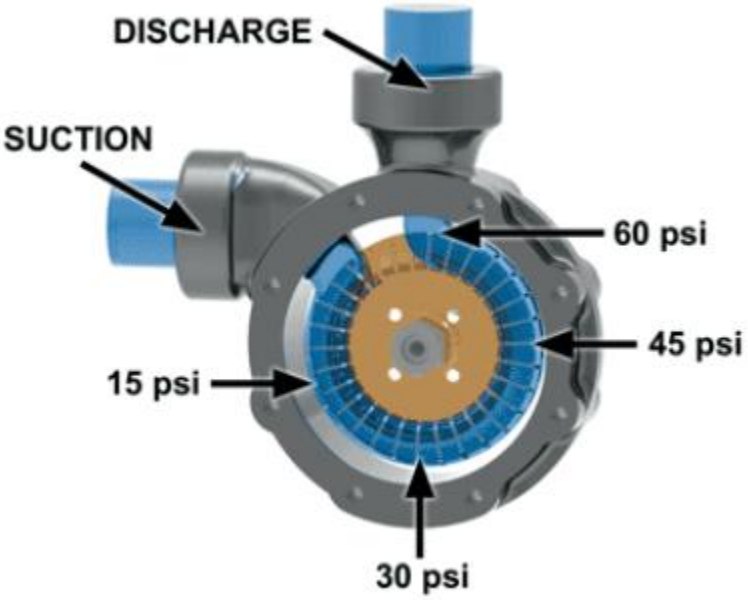
Stationary diffuser casings are typically used for multistage, high discharge pressure pumps for maximum pump reliability and where high efficiency is of major importance. These are the types of pumps found for boiler feed in high pressure steam plants. In the stationary diffuser type, the impeller discharges into a uniform ring of nozzles that increase from smaller at the entrance to wider at the exit, and consequently the radial loading on the impeller is balanced.

The runner of the stationary diffuser pump is surrounded by gradually-expanding passages formed by stationary guide vanes. In this type of casing, the velocity of the liquid leaving the impeller is converted more completely into pressure than in the volute type, making its efficiency higher. The added expense and more complicated construction of the stationary diffuser pump, compared with a single volute, are generally not considered justifiable for the efficiency advantage alone, except in large, high-pressure pumps.



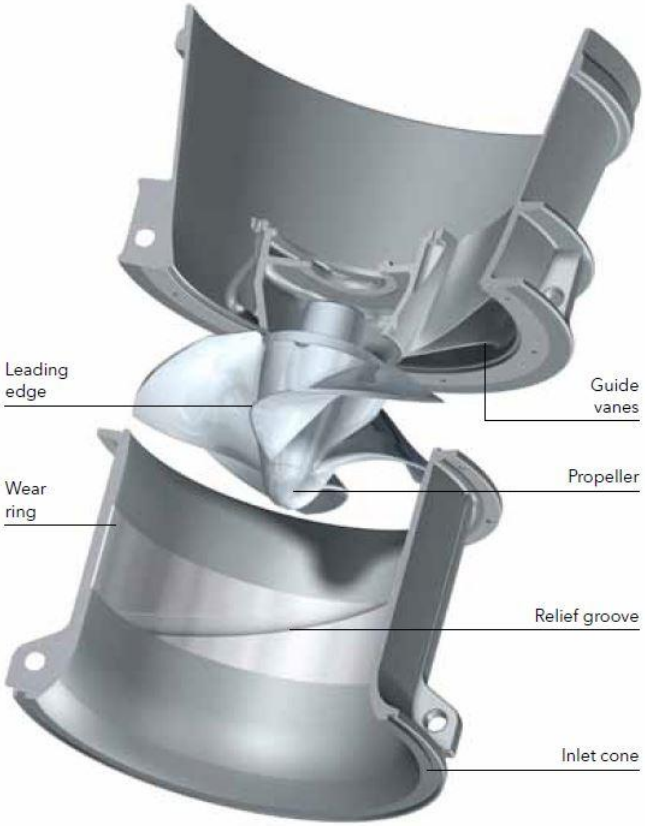
TURBINE OR REGENERATIVE PUMP





The turbine pump is a type of centrifugal pump that has impeller vanes equally distributed around the impeller wheel. The water can enter the center of the impeller and then through a spiral passageway into the vanes of the impeller, or the water can enter the vanes from the side. The vanes spin the water with sufficient force to raise the discharge pressure of the water about four times the suction pressure. As the vane passes the partition that separates the suction from the discharge, the water is sent out the discharge pipe. The casing of the turbine pump is circular rather than the volute shape of the ordinary centrifugal pump. The turbine has a higher lift capacity than any of the other centrifugal pumps but it has a small water capacity. They are a low-capacity high-head type used on heads up to 5400 ft and in capacities up to 150 gpm. Regenerative turbine pumps are known by several names, such as vortex, peripheral and regenerative. None of these give a true description of the pump, but regenerative turbine is the nearest.

PROPELLER or AXIAL FLOW PUMPS



An propeller or axial-flow pump, is a type of pump that consists of a propeller (an axial impeller) within a pipe. The propeller can be driven directly by a sealed electric motor in the pipe or by an electric motor or engines mounted to the pipe from the outside or by a right-angle drive shaft that comes though a seal in the side of the pipe.

An axial flow pump has a propeller-type of impeller running in a casing. The pressure in a propeller pump is developed by the flow of liquid over the blades of impeller. The fluid is pushed in a direction parallel to the shaft of the impeller.

The main advantage of a propeller pump is that it has a relatively high discharge flow at a relative low discharge pressure. It can pump up to 3 times more water and other fluids at lifts of less than 12 feet as compared to the more common radial-flow or centrifugal pump. It also can be easily be adjusted to run at peak efficiency at low-flow/high-pressure and high-flow/low-pressure by changing the pitch on the propeller on some models.

RECIPROCATING PUMPS

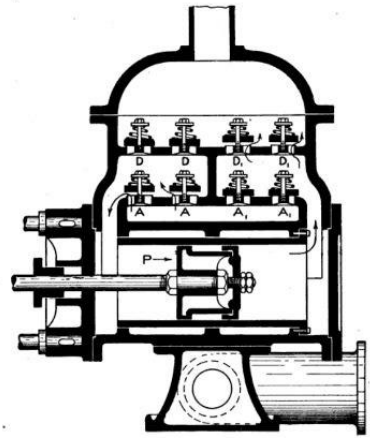
The direct acting steam pump has the steam piston solidly connected to the liquid piston by piston rods. While the rod assembly may be made of the separate pieces of two rods screwed into a crosshead, they create a single connection between the steam piston and the water piston so that if the steam piston moves a certain distance, the water piston moves in the same direction by the same amount. Direct acting steam pumps are divided into two categories, the Simplex and the Duplex. The Simplex has one steam and one water piston while the Duplex has two steam and two water pistons. The water end of both the Simplex and the Duplex pumps can be further subdivided into:

1. Piston
2. Plunger
    a. outside-end packed
    b. outside-center packed
    c. inside packed

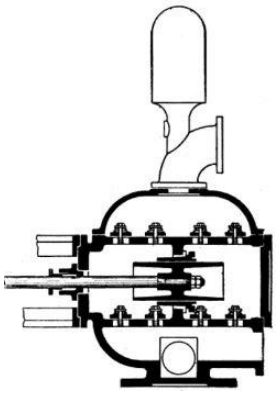
Plunger pumps have the advantage of being able to adjust the leakage past the plunger from the outside.

Direct acting pumps are double-acting which is to say that while one side of the piston is pulling water into the cylinder, the other side of the piston is pushing the water out of the pump. The movement of the water in and out of the pump is controlled by spring loaded valves. Three different methods of arranging the valves are used:

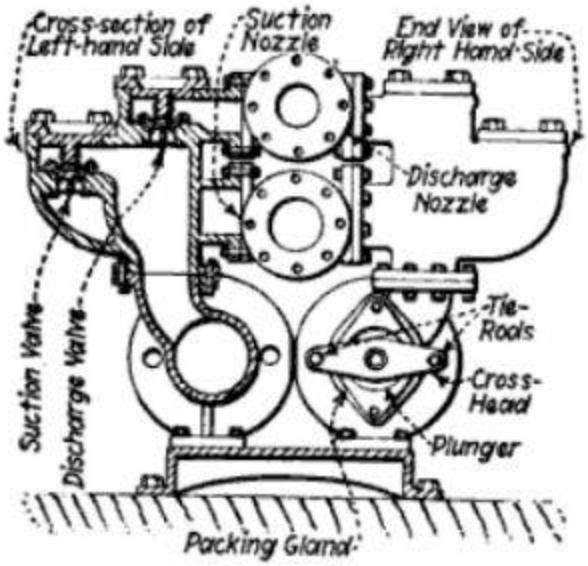
1. Discharge valves on top of the suction valves, both sets of valves sitting above the pump cylinder. (turret assembly)



2. Discharge valves above the pump cylinder with the suction valves below the pump cylinder.

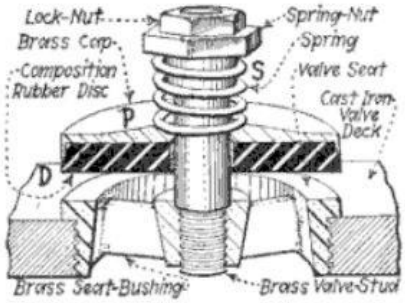


3. Discharge valves above but to the side of the suction valves, both sets of valves sitting above the pump cylinder. (pot valves)



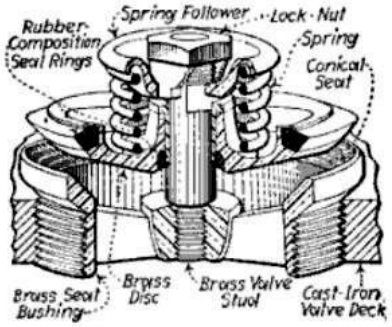
Water-End Of Duplex Outside-Packed Plunger-Pump Equipped With Pot Valves.

Pump valves are spring loaded and are made from different materials depending upon the discharge pressure and the liquid being pumped.



Flat-Seated Pump-Valve With Composition Rubber Disc.

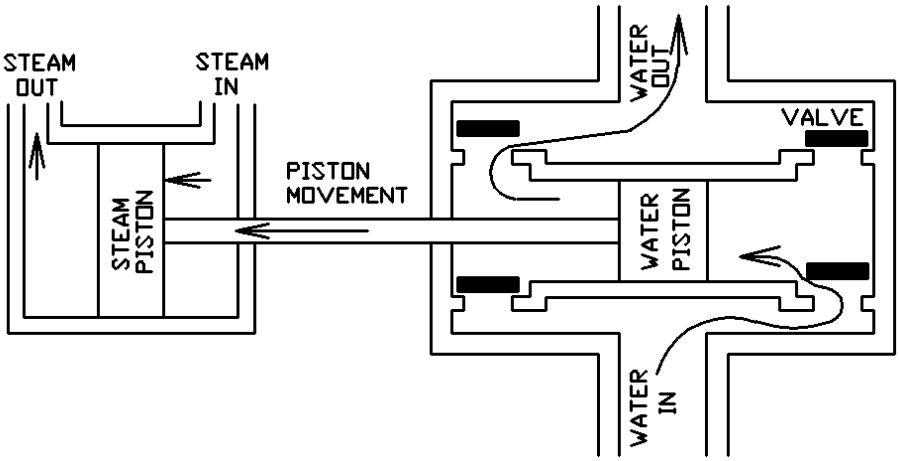
1. Soft Rubber...vacuum to 75 psi
2. Hard rubber composition...75 to 150 psi
3. Vulcanized rubber composition...150 psi to 300 psi
4. Brass, drop forged iron, drop forged bronze, hardened nickel, stainless steel, monel,...over 300 psi

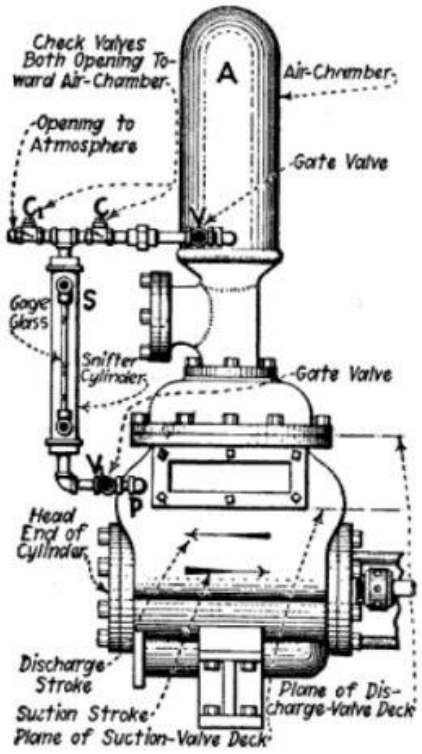


Conical-Seated Pump-Valve With Brass Disc.

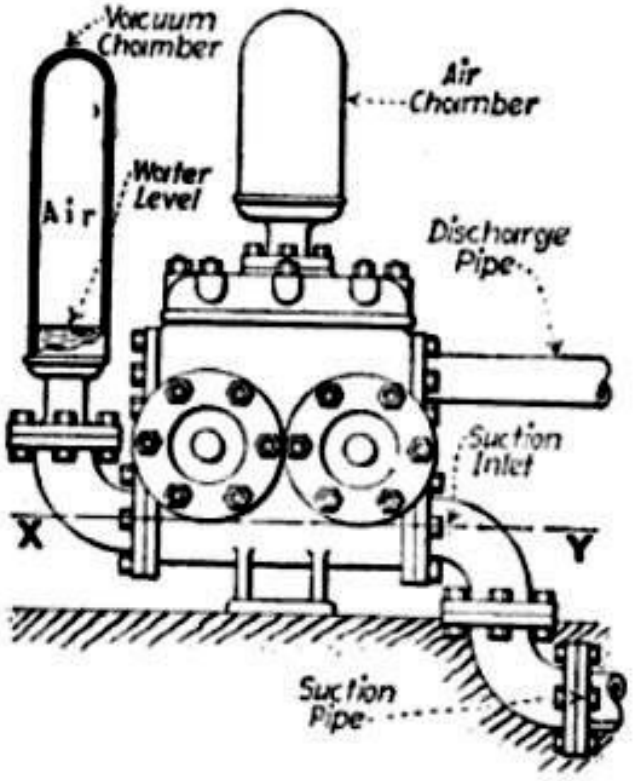
Rubber is vulcanized by treating it with sulfur compounds to give the rubber greater elasticity, strength, and stability.

When metal valves are used the seats should be made of the same material as the valves to prevent electrolysis.





Snifter For Replenishing Air-Chamber Of Direct-Acting Steam-Pump.



Air chambers are sometimes placed on the suction or discharge sides of the pump to help even out the pulsations of the reciprocating pump. When air chambers are used on the suction side of the pump they are known as vacuum chambers. Air is compressible while water is not. As the water is discharged from the pump, the increase in pressure forces water higher into the air chamber, compressing the air and storing energy. As the discharge valves of the pump close, the air forces the extra water in the air chamber out into the discharge line, releasing the stored energy in the air chamber as the pressure equalizes. This works to smooth the sharp pressure rises and drops that would occur if the air chamber were not present. Duplex pumps have inherently smoother flow characteristics than simplex pumps due to having two water pistons, one of which starts to operate before the other has finished its stroke, so there is always an overlap of one pressure rising as the other falls.

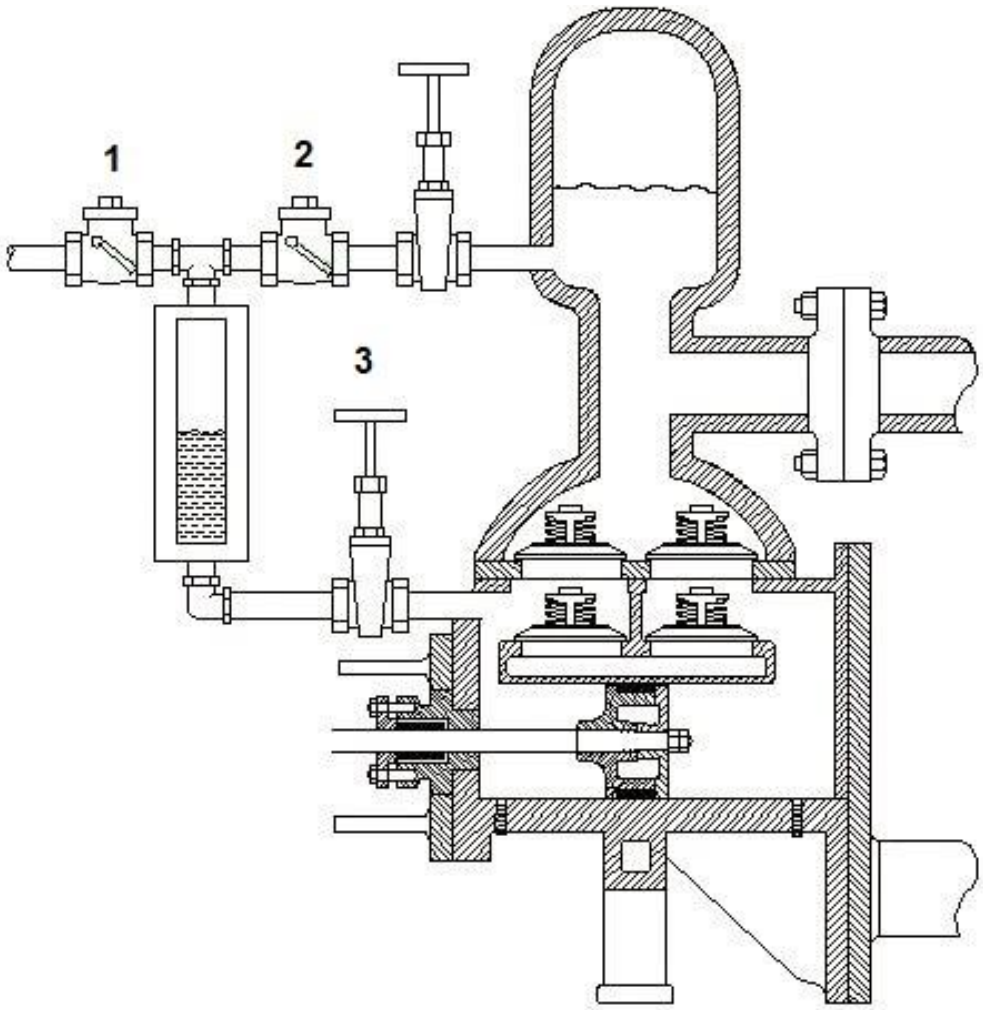
The water level in the air chamber should not be more than 1/4 the height of the air chamber. Air can be absorbed into the water and the water level inside the air chamber rises accordingly.

Air chamber volumes are as follows:

Simplex Pumps: From 2 to 3 1/2 times the volume of the water piston displacement.

Duplex Pumps: From 1 to 2 1/2 times the water piston displacement.

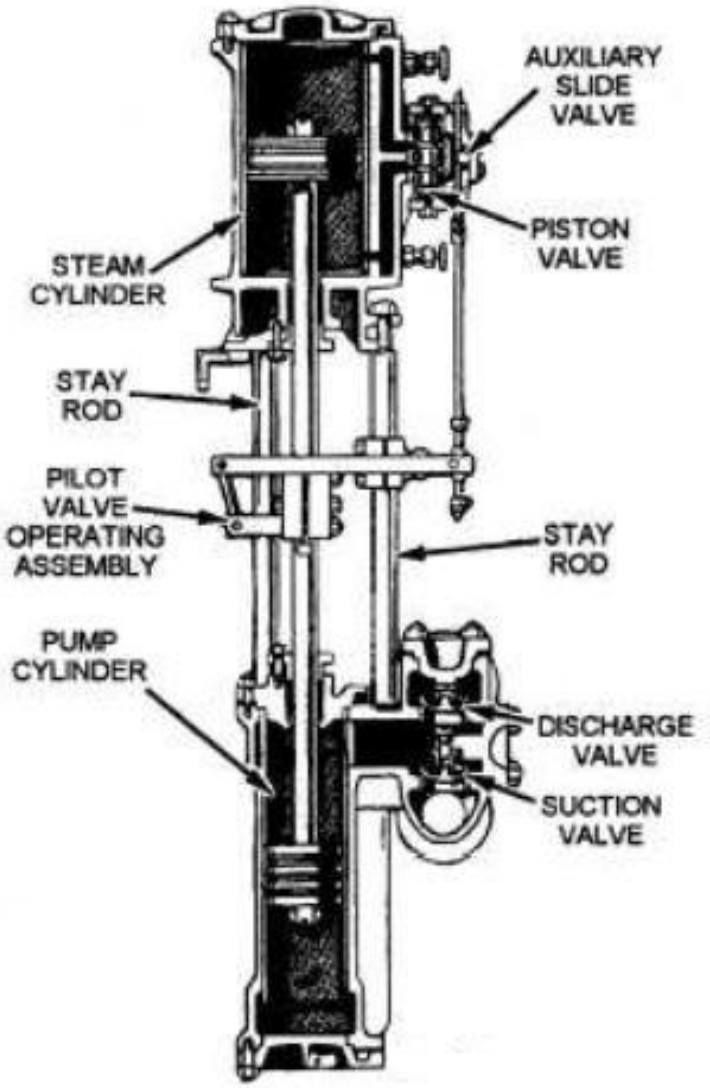
THE SNIFTER



In order to maintain the air charge in the air chamber, a 'snifter' is sometimes used. A snifter is a cylinder with a gauge glass that is piped between the suction and discharge valves on one end and the air chamber on the other end, two check valves in series control the movement of air from the outside into the air chamber. The sequence of events is as follows: As the piston moves to the right in figure, the decrease in pressure pulls the suction valve up and also opens check valve 1 as atmospheric pressure overcomes the suction water pressure. Check valve 2 does not open because the water pressure in the air chamber holds check valve 2 closed. As the piston reverses and the water pressure building underneath the discharge valves closes check valve 1 and opens check valve 2, forcing the air from the snifter cylinder into the air chamber. As the water piston continues its travel to the left, the discharge valves open and force check valve 2 closed. Gate valve 3 should be adjusted so that the water level in the snifter sightglass pulsates within the length of the sightglass.

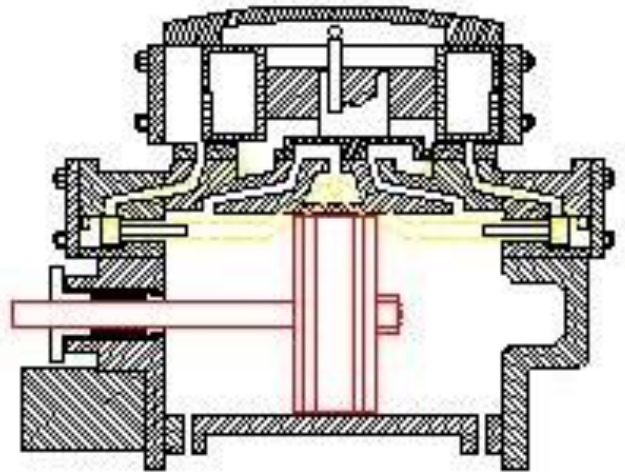
SIMPLEX PUMPS

A simplex pump consists of a single steam cylinder and a single water cylinder. Steam admission and exhaust is controlled by a small floating main piston slide valve, not to be confused with the steam piston or water piston. Sometimes the main piston slide valve is called a "spool" valve because it can resemble an empty spool of thread. This main piston slide valve is "steam thrown" which is to say that the steam pressure pushes the valve from one end of its chamber to the other.

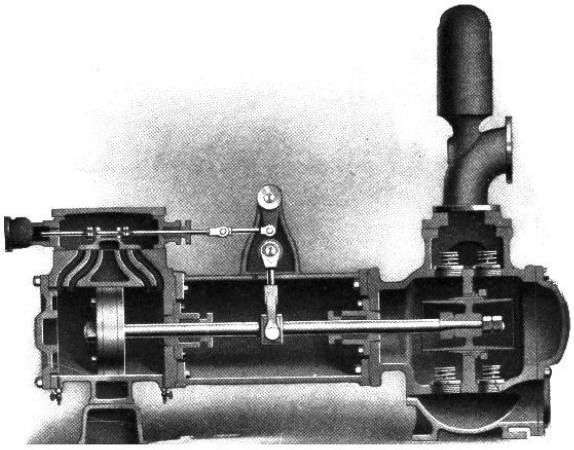


Control of the steam that pushes the main piston slide valve is accomplished by an auxiliary piston slide valve or pilot valve that is in turn operated by linkage hooked to the steam piston rod. As the steam piston rod moves back and forth, linkage attached to the steam piston rod contacts tappets that are attached to the auxiliary piston valve rod. As the auxiliary piston slide valve reciprocates back and forth, it allows steam to flow through passages in the steam chest pushing the main piston slide valve from one end to the other. As the main piston slide valve moves from one end of its chamber to the other, it controls the steam behind the steam piston, pushing the steam piston back and forth.

The steam piston is of course hooked to the steam rod which starts the cycle all over again. Length of the stroke can be changed by adjusting the distance of the tappets farther apart or closer together. Because of this, the pump should be adjusted for a full stroke and if properly adjusted, the simplex pump will not "short stroke" as the duplex pump can. The Simplex pump will sometimes stop for no apparent reason.

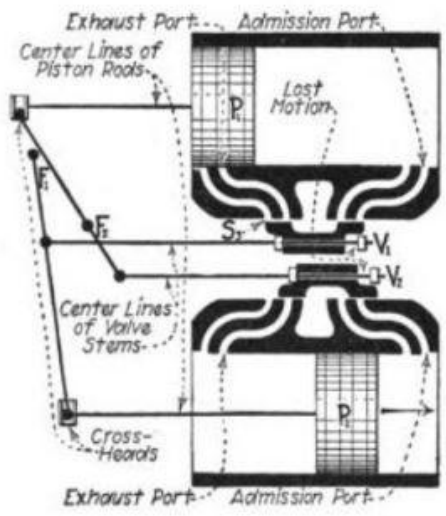


DUPLEX PUMPS

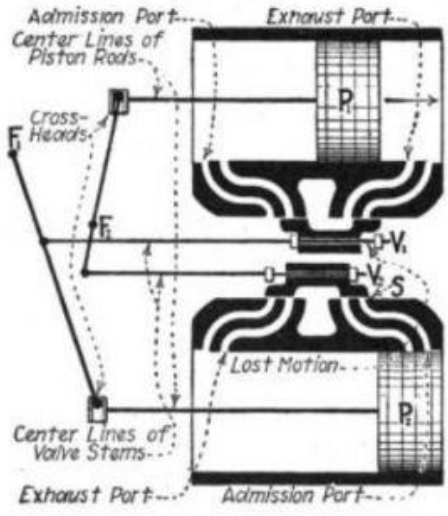


A duplex pump is basically two independent double-acting reciprocating pumps arranged side by side, with the motion of the piston in one cylinder controlling the movement of the steam valve in the other. The duplex pump was invented by Henry Worthington in 1859. As one piston ends its stroke and the water pressure begins to fall, the other piston starts its stroke and keeps the discharge pressure nearly equal. There are two ends to each side of the duplex pump. One end has the steam piston and D-slide valve that controls the steam flow in that end of the pump. The other end has the water piston and water valves that control the water flow through the pump. There are four valves, two suction and two discharge for each water piston for a total of eight. The steam and water ends are connected by piston rods.

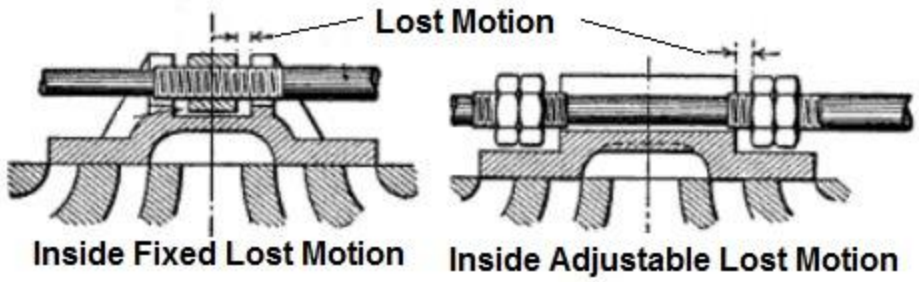
The piston rod of one side moves the steam valve of the opposite side in the same direction. When the first pump has completed its stroke, it must pause until its own steam valve is actuated by the movement of the second pump piston rod before it can make its return stroke. Because one or the other steam cylinder port is always open, there is no "dead center" condition; hence, the pump is always ready to start regardless of the position it is stopped in. There is a rhythm to the stroke-pause-stroke that makes it unique among steam pumps. The genius of the pump design is that it allows an almost continuous flow of water without the added room and expense of a flywheel to keep the pump operating.

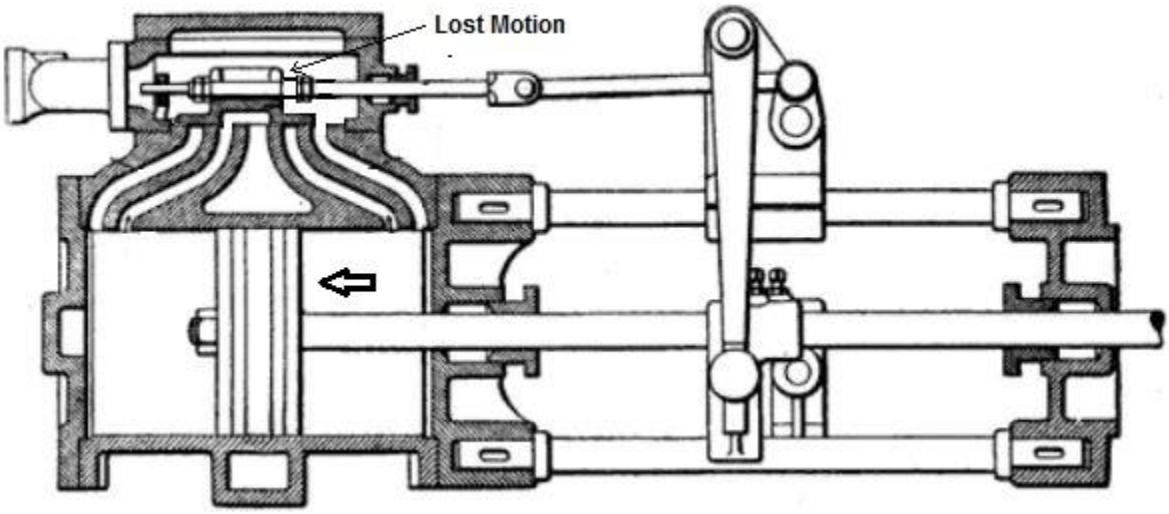


Piston P_1 At End Of Inboard Stroke And On Point Of Reversal. Piston P_2 Approaching End Of Head-End Stroke.



Piston P_2 At End Of Head-End Stroke And On Point Of Reversal. Piston P_1 Approaching End Of Head-End Stroke.





Outside Adjustable Lost Motion

Duplex pump steam valves have lost motion. Lost motion occurs when the steam valve is not moving due to the space between the top of the steam valve and the adjusting nut that pushes the valve in one direction or pulls it back in the other direction. The reason for lost motion is threefold:

1. It is used to adjust the length of the piston stroke.

2. Lost motion creates continuous piston travel.

3. It prevents the pump from stopping in a position from which it cannot be restarted. If you admit steam to the steam chest from wherever position it was in when it was stopped, it should immediately restart. Continuous piston-travel is secured by preventing simultaneous reversals of the piston-strokes. Assurance against a. dead—center or non-starting position is due to the fact that when either steam-valve covers all four ports, the opposite valve leaves an admission and an exhaust port wide open. This feature of the duplex pump renders it well adapted for periodic operation under governor control.

There are 3 arrangements for lost motion

1. Inside Fixed
2. Inside Adjustable
3. Outside Adjustable

SETTING THE VALVES OF A DUPLEX PUMP.

Setting the valves on a Duplex Pump with a single slide valve nut between the lugs of the steam valve is accomplished by the following procedure.

1. Shut off the steam and water main suction and discharge stop valves to the pump.

2. Open the drains on the steam cylinders to ensure the cylinders are free of condensate.

3. Open the drains on the water cylinder to drain all water from the cylinder.

4. Move the piston rod on one side by hand toward the left steam cylinder until the piston strikes the left end of the steam cylinder. If the pump is too large to move the piston rod by hand, use a pry bar against the crosshead in order to move it. Do not pry against the lever.

5. Mark a line on the piston rod with a pencil or soapstone where the rod enters the steam stuffing box packing gland.

6. Move the same piston rod to the right so that it strikes the end of the steam cylinder on the opposite end.

7. Measure from the edge of the steam stuffing box packing gland to the line that you drew. Divide the distance in 1/2 and make a pencil or soapstone mark on the piston rod at the 1/2 way point.

8. Move the steam piston rod to the left until the 1/2 way mark on the rod lines up with the steam stuffing box packing gland. This will place the steam piston at midpoint between the two ends.

9. Follow the same procedure to place the piston rod on the other side at midpoint.

10. Remove the cover from the steam chest.

11. Remove the link pin that holds the knuckle eye and the link eye together. Remember that the valve on one side controls the piston for the other side.

12. Place the slide valve so that it covers both steam ports completely.

13. Hold the slide valve nut exactly centered in the space between the two slide valve lugs with one hand.

14. With the other hand adjust the distance between the knuckle eye and the link eye by turning the valve rod through the screw thread on the nut. When the knuckle eye and the link eye line up, replace the link pin.

15. Follow steps 11 through 14 for the slide valve on the other side.

16. When both pistons are in midpoint and both slide valves completely cover the steam ports with the slide valve nuts in the exact center between the lugs on the slide valves, the valves on the Duplex pump are correctly set.

17. Push one slide valve against the slide valve nut so that a steam port is open. Failure to do this will keep the pump from starting. Replace the steam chest cover and the pump is ready to start.

Important points to remember about duplex pumps are:

1. If you reduce the amount of lost motion the pump will short stroke, it will not travel the full distance from one end to the other.

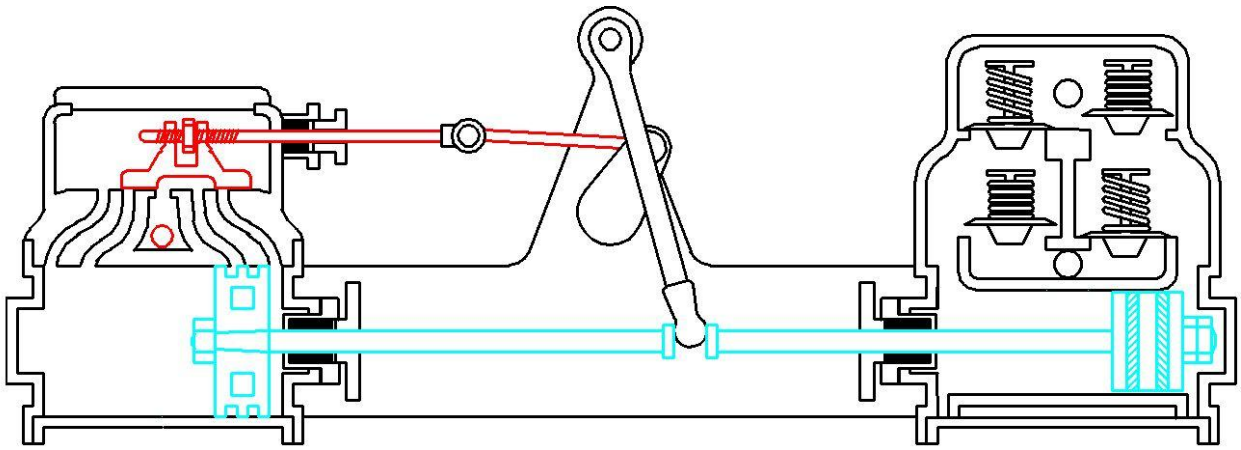
2. One of the questions often asked by Boiler License Examiners is how can a pump that is getting steam from the boiler force water back into the same boiler? How can it get the water pressure high enough? The answer is that the pump piston is smaller than the steam piston of the pump. This allows steam to operate against the greater square inches of the steam piston and since the total force acting against both pistons is equal, the water piston develops higher pounds per square inch than the boiler pressure and water can flow into the boiler.

3. Duplex pumps are classified by STEAM X WATER X STROKE. This means that a 6 X 4 X 6 pump has a 6 inch diameter steam piston, a 4 inch diameter water piston, and a 6 inch stroke.

4. Lap is defined as the amount that the outside edge of the valve overlaps the port opening when the valve is in mid-position. Steam engine D-slide valves have lap. Duplex pump D-slide valves have no lap.

5. For three reasons duplex pumps are steam wasters. First, because of the wasted clearance of steam in the cylinder whose piston is not traveling its full stroke. Second, because duplex pumps have double the number of ports, and steam spent in filling ports is steam wasted. Third, because the design of the pump requires they have no lap, the expansive power of steam cannot be used.

6. A well maintained duplex pump can last 50 years or more.



Starting a Duplex Pump

1. Make sure all the valves on the suction line going to the pump and the discharge line from the pump to the boiler are open.

2. Open the water discharge valve on the pump.

3. Open the water suction valve on the pump.

4. Open the steam exhaust valves on the pump.

5. Open the cylinder drains on the steam end.

6. Start admitting steam slowly to the pump.

7. Turn on the hydrostatic lubricator if so equipped.

8. The pump will start running slowly for a few minutes until the pump is warmed up.

9. Keep opening the steam valve until the pump is up to full speed.

10. Close the drains.

11. Adjust the packing so that steam does not blow out the steam end or water from the pump end but do not over-tighten or else the packing will overheat and have to be replaced.

Reasons why a Duplex pump will not operate correctly

1. The steam inlet or outlet valves are closed.

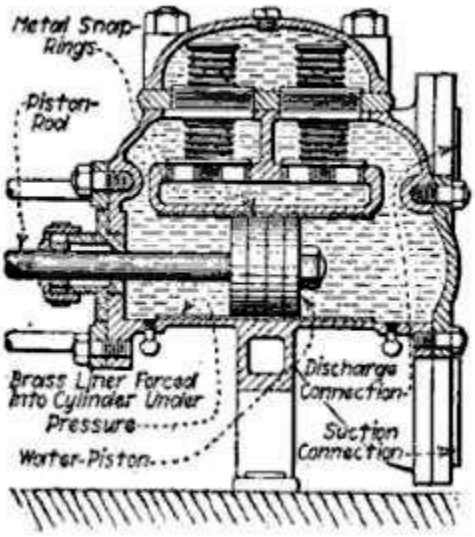
2. The water inlet or outlet valves are closed.

3. The packing glands are too tight.

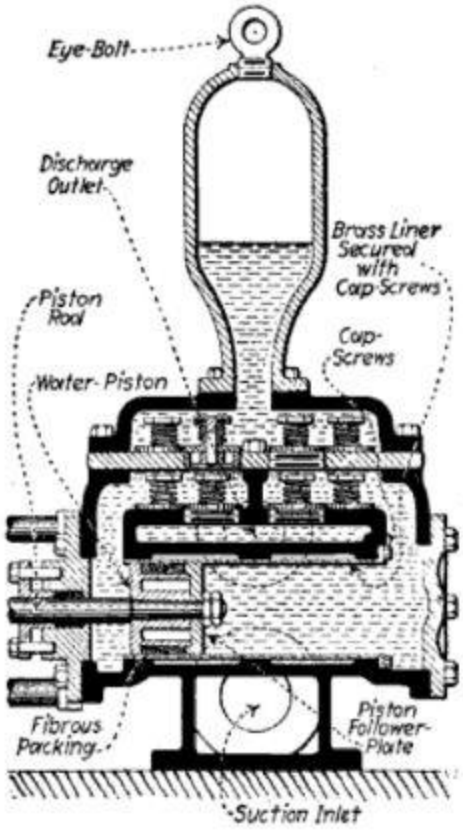
4. The suction lift is too high.

5. The steam pressure is too low.

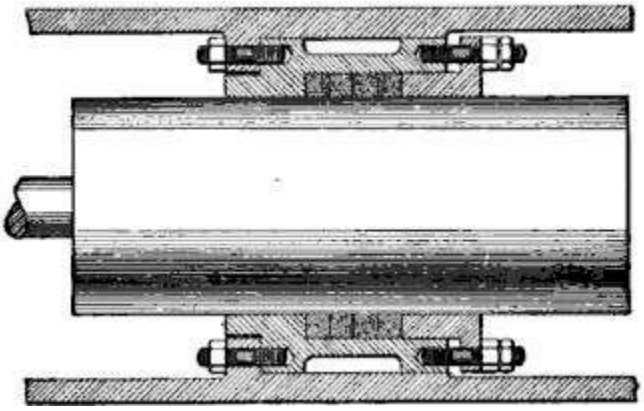
6. There are leaks in the suction line.



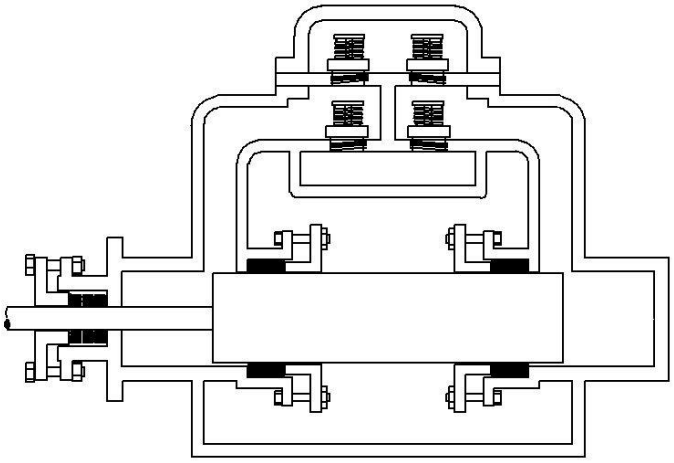
Plain piston with piston rings



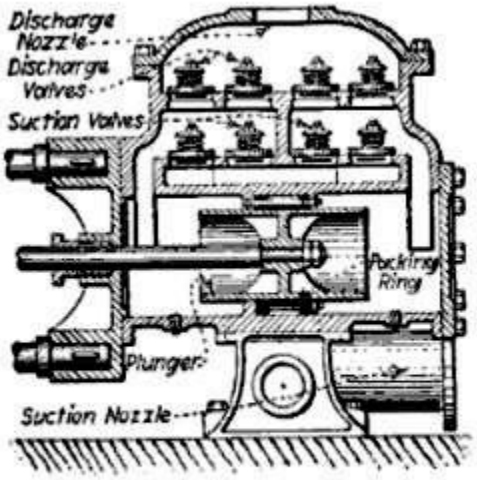
Water-End Of Direct-Acting Steam-Pump With Fibrous-Packed Water-Piston.



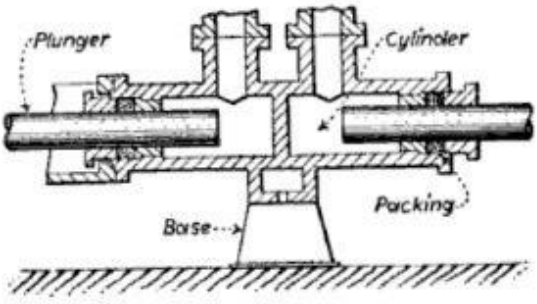
Plunger with Inside Fibrous Packing



End Packed Plunger Pump

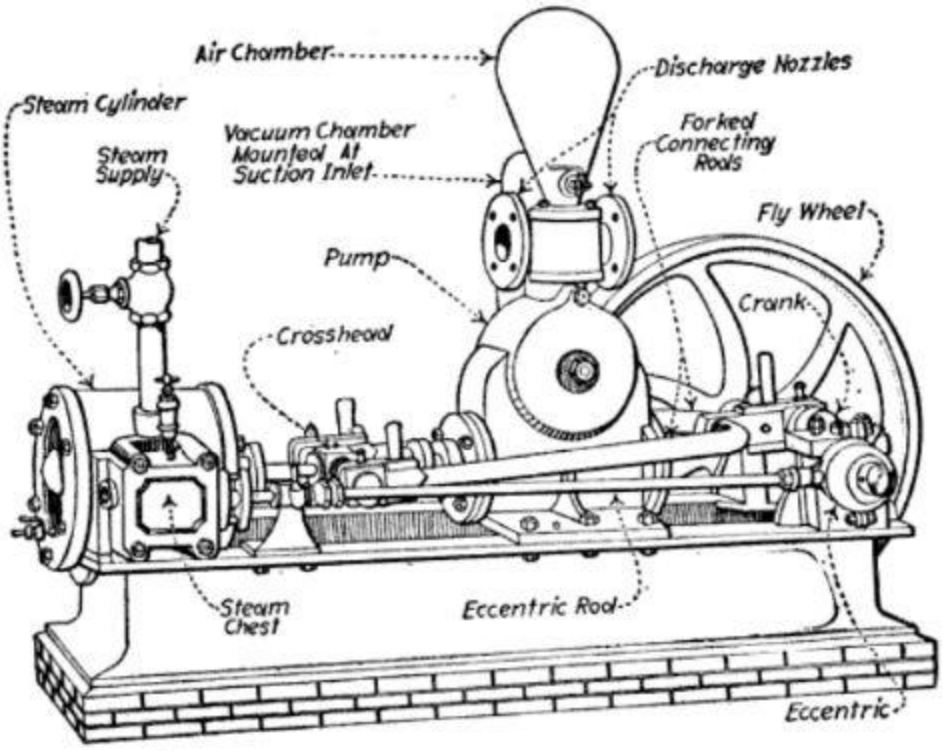


Pump-Plunger Inside-Packed With Metal Ring.



An Outside End-Packed Plunger-Pump.

CRANK and FLYWHEEL PUMP



Steam-Driven Crank-And-Fly-Wheel Pump.

Crank-Action Pumps depend upon flywheels and the circular motion of a crankshaft. The Crank and Flywheel pumps has the reciprocating motion of the pump piston derived from the piston movement in a steam cylinder but is dependent upon the inertia of a flywheel to drive the pump over dead center.

Advantages of the Crank and Flywheel pump are:

1. The D-slide valve of the steam engine has lap and can use steam expansively, and is more efficient in the use of steam than a duplex pump.

2. It has a more uniform stroke than a duplex pump.

Disadvantages of a Crank and Flywheel pump are:

1. It takes up more room than a duplex pump and can stop in a position where the flywheel needs to be turned in order to get it to start.

2. It has more parts and complexity than a duplex pump

PACKING AND GASKET MATERIAL

Packing is used to seal fluid leakage from around the shaft of pumps or the stems of valves. A number of rings of packing are placed into a stuffing box to control the leakage of fluid past the packing. A lantern ring is sometimes used to replace one ring of packing in pumps. The lantern ring has passageways in the ring that allow water to flow through and cool the packing and the shaft. Square braided packing consists of interwoven fibers of various materials. As the packing gland is tightened the packing is compressed. The braid is squeezed together to form a seal against fluid leakage. Lubricant is integral with the packing to prevent the packing from overheating. The lubricant is eventually used up and the packing must be replaced. The procedure to replace the packing in a pump is as follows:

Repacking a Pump

1. Shut off the pump and close the inlet and outlet valves.

2. Remove the packing gland follower and the packing gland.

3. Remove the old packing using a packing puller with a corkscrew on the end of a flexible metal handle. Count the rings as you pull them out. If the stuffing box has a lantern ring, you want to make sure that the lantern ring will be under the water inlet and outlet when reinstalled. When the lantern ring is removed, use a stiff wire with a 90 degree bend on the end inserted into the stuffing box to ensure that the holes for the water lines match up with the lantern ring. An average stuffing box would consist of 3 rings of packing, a lantern ring, and then 2 more pieces of packing.

4. Cut each piece of new packing to reassemble into the stuffing box after all the old packing is removed. The packing is cut at an angle so that the fluid has to travel a longer distance through the packing before it reaches the next packing ring. Note carefully the correct way to cut the packing. As you look at the packing from the top, the cut will appear as a diagonal line. As you look at the packing from the end of the shaft, the cut will appear as a straight line. Cut one piece of packing until you achieve a perfect fit around the shaft. Unroll the piece of packing that fits perfectly and nail the piece of packing flat on a board.

Using the first piece of packing as a guide, place the packing from the roll next to the piece of packing nailed to the board and cut enough pieces to fit the stuffing box. Using this method the packing should be the same length and cut at the same angle as the first. Rolling the packing around the shaft and cutting through all of it at the same time will not give the exact lengths needed for a good repacking job.

5. A single edged razor blade does a good job of cutting the packing. Most packing knives will not hold the edge needed to cut through multiple lengths of packing. The knife should cut through the packing cleanly without tearing any strands. Some types of packing tend to fray on the ends. Wrapping the end with masking tape before cutting will reduce the problem of fraying. A good packing knife can be made by grinding the teeth from an old power hacksaw blade and wrapping one end with tape for a handle. Be sure to dip the blade in water numerous times while grinding an edge on the blade to avoid overheating and softening the metal.

6. Clean the stuffing box before installing the new packing. The cut for the next piece of packing installed is placed at either 180 degrees or 120 degrees from the previous piece of packing. Either method will work.

7.Install the new packing taking care to replace the lantern ring in the correct location. The packing rings should not extend past the face of the stuffing box. Remove the last piece of packing if this occurs rather than trying to force the packing into the box by tightening. Someone may have previously packed the pump and put one extra piece of packing in the end when all the old packing was compressed from loss of lubricant rather than properly repacking the pump.

8. Keep the nuts on the packing gland finger tight when first reopening the valves and starting the pump. Fluid leakage may be great at first. This is alright. Wait until the packing has heated up and expanded before tightening the nuts. Tighten each nut the same amount on each side so that the pressure is equalized around the packing gland. Tighten until a steady 1/16 inch stream of fluid is leaking past the gland and then wait. The fluid should slow down as the packing heats up. If not, continue to tighten each nut the same amount until about one drop is coming from the gland about every 5 seconds. A stuffing box is never tightened so that no leakage occurs while running. Some leakage must occur to ensure that the shaft will remain cool. Check the temperature of the outside of the stuffing box during and after adjustment. If you cannot comfortably leave your hand on the stuffing box of a pump with a fluid temperature of 70 degrees or less, the packing is too tight.

PACKING MATERIAL

Square braided asbestos with graphite or grease as a lubricant was universally used with good results for many years. It has resistance to mild chemicals and solvents and can be used for temperatures up to 500 degrees Fahrenheit. Asbestos is a naturally occurring mineral. It is a rock made up of numerous small strands of short fibers. These strands are woven around cotton yarn or wire to get the necessary length to be interwoven into the square braided packing. This interweaving gives the packing flexibility and allows the infusion of the lubricant between strands. Soaking fiber packing in graphite and water before inserting will help keep the packing cool.

Inhaling asbestos fibers can cause cancer known as mesothelioma. Concern over this has led to the use of different materials for packing. Teflon, graphite yarn, and Kevlar are being used in place of asbestos. Kevlar is the same material used in bulletproof vests.

Because of the absence of a packing as good as asbestos, many powerhouses will pay to have the pump shafts metalized and trued on a lathe and have mechanical seals installed. Mechanical seals work great as long as they work, but when they fail, the leak is so bad you normally have to immediately take the pump out of service. With packing, usually another ring of packing can be installed until the pump can be taken out of service at your convenience.

Garlock was one of the biggest suppliers of asbestos packing. Lawsuits caused the company to file for Chapter 11 bankruptcy protection in 2010. Some news references have cited Garlock Sealing Technologies as "one of the most sued companies in American history, with the overwhelming majority of lawsuits involving asbestos."

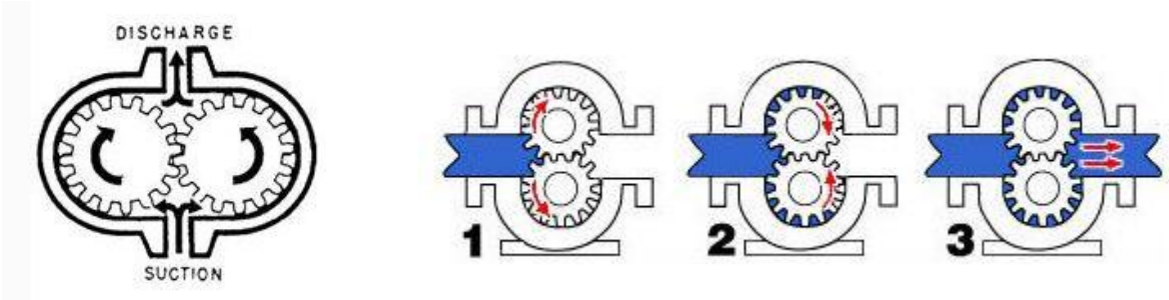
ROTARY PUMPS

Rotary pumps are capable of pumping more fluid than reciprocating pumps. The rotary pump is a positive-displacement pump. This means that for each revolution of the pump, a fixed volume of fluid is moved regardless of the resistance against which the pump is pushing. Any blockage in the system could quickly cause damage to the pump or a rupture of the system. Be sure that all valves are open before starting a positive displacement pump. Rotary pumps require a relief valve to protect the pump and piping system. The relief valve lifts at a preset pressure and returns the system liquid either to the suction side of the pump or back to the supply tank or sump. Piping back to the tank is better because the pump will not churn the fluid and overheat.

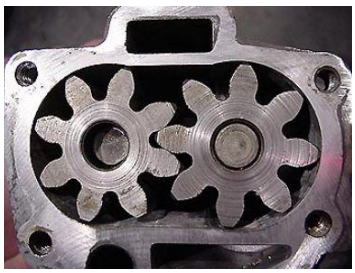
Rotary pumps are different from centrifugal pumps in that they are self-priming. A rotary pump operates within limits with the pump located above the source of supply as long as atmospheric pressure can overcome the suction lift.

GEAR PUMPS

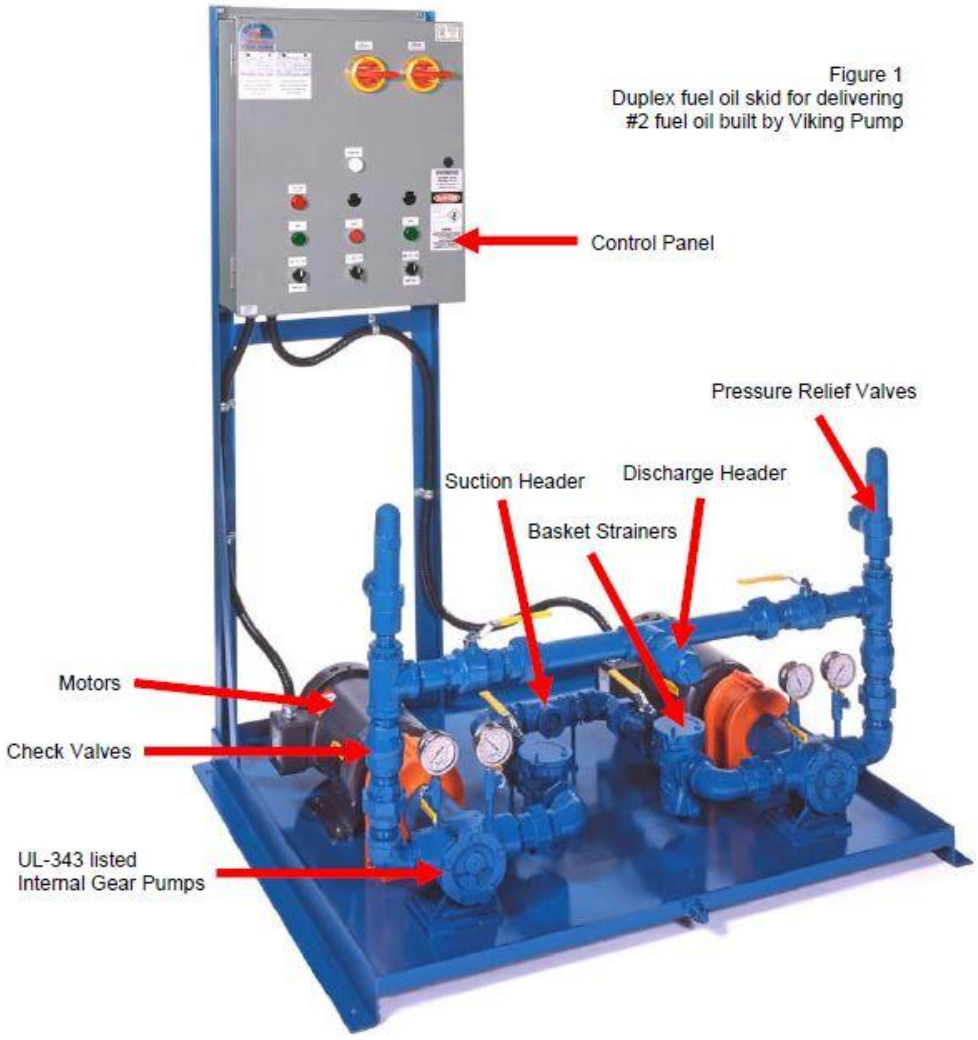
Gear pumps are useful for pumping oil and other heavy viscous liquids. In the engine room, rotary gear pumps are used for handling lube oil and fuel oil and are suitable for handling liquids over a wide range of viscosities. Gear pumps are designed with very small clearances between rotating parts and stationary parts to minimize leakage backflow from the discharge side back to the suction side. Rotary pumps are designed to operate at relatively slow speeds to maintain these clearances; operation at higher speeds causes erosion and excessive wear, which result in increased clearance with and a decrease in pumping capacity.



The simple gear pump has two spur gears that mesh together and revolve in opposite directions. One is the driving gear, and the other is the driven gear. Clearances between the gear teeth (outside diameter of the gear) and the casing and between the end face and the casing are only a few thousandths of an inch. As the gears turn, the gears unmesh and liquid flows into the pockets that are vacated by the meshing gear teeth. This creates the suction that draws the liquid into the pump. The liquid is then carried along in the pockets formed by the gear teeth and the casing. On the discharge side, the liquid is displaced by the meshing of the gears and forced out through the discharge side of the pump. Operating a rotary gear pump far below its rated speed when handling low viscosity liquids, will cause its volumetric efficiency percent of volume being actually being pumped to decrease to where the pump no longer develops flow.



Use of gear pumps include but are not limited to diesel engine fuel pumps, heavy oil fuel pumps, lube oil supply and transfer pumps, dirty oil pumps, and centrifuge supply pumps.



Oil Pump Skid with major components installed

Gear pumps are designed for slower speeds, lower pressures, and materials designed for the anticipated temperature.

Install the pump as close as possible to the supply tank.

Leave working space around the pumping unit.

Use large, short, and straight suction piping. "Short and fat" pipes are excellent.

Install a strainer in the suction line.

Double-check alignment after the unit is mounted and the piping is hooked up.

Provide overpressure protection for the discharge side of the pump, either in-line or on the pump.

Extend service life with preventive maintenance procedures such as periodic lubrication, adjustment of end clearance, and examination of internal parts.

Obtain, read, and keep the maintenance instructions furnished with your pump, drive, and other system equipment.

Installing a vacuum gauge and a pressure gauge on or near the pump will also help lengthen service life. Gauges provide a window into what is happening inside the pumping system.

Properly interpreted readings can give clues to the nature of many problems. Long-term readings will show gradual changes taking place within the system.

Given the availability of certain fuels at any particular time, many fuel oil systems now accommodate various fuels (#2 through # 6 fuel oil for example). Each fuel oil differs slightly in properties and these differences place unique demands on the system. Be sure to discuss these differences with your pump/system supplier.

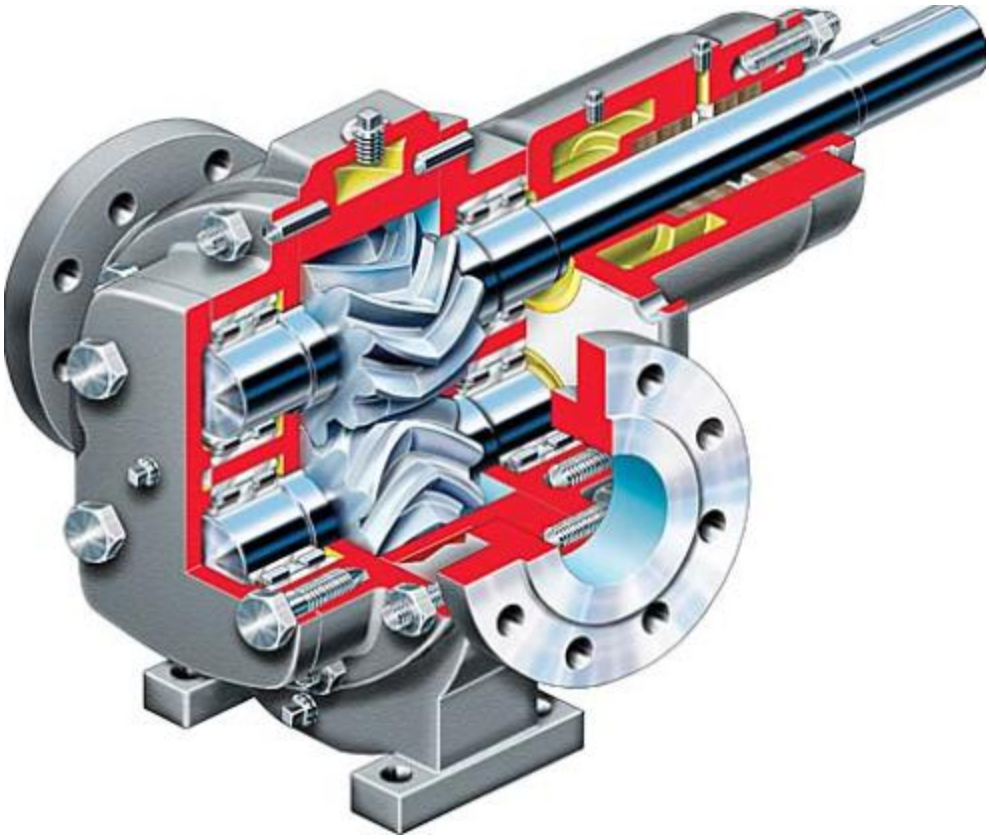
DO NOT…
Run a pump at faster than approved speeds.

Run a pump at higher than approved pressures.

Run a pump at higher than approved temperatures.

Use extra large, extra long suction line with a suction lift.

HERRINGBONE-GEAR



Designed to handle viscous fluids, these are rugged pumps that provide high efficiency, pulse-free pumping of greases, polymers, and petroleum for Utilities and Power Generation

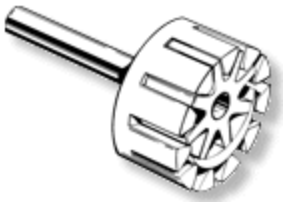
Double Helical Herringbone Gears provide quiet, pulsation-free flow with better load carrying ability, greater strength and minimum hydraulic shock.

High Speed Pump Capability eliminates need for expensive speed reduction accessories and allows the use of off-the-shelf motors.

Between Bearing Design virtually eliminates shaft deflection, even while accommodating heavy, highly viscous loads.

Inherently Hydraulically Balanced Design eliminates end thrust and the need for thrust bearings.

INTERNAL GEAR PUMP



While they are often used on thin liquids such as solvents and fuel oil, they also excel at efficiently pumping thick liquids. The pump has a wide temperature range as well, handling liquids up to 750 degrees Fahrenheit. This is due to the single point of clearance between the ends of the rotor gear teeth and the head of the pump. This clearance is adjustable to accommodate high temperature, maximize efficiency for handling high viscosity liquids, and to accommodate for wear.

The internal gear pump is non-pulsing, self-priming, and can run dry for short periods. They're also bi-rotational, meaning that the same pump can be used to load and unload a tank of liquid. Because internal gear pumps have only two moving parts, they are reliable, simple to operate, and easy to maintain.

1. Liquid enters the suction port between the rotor (large exterior gear) and idler (small interior gear) teeth. The arrows indicate the direction of the pump and liquid.

2. Liquid travels through the pump between the teeth of the "gear-within-a-gear" principle. The crescent shape divides the liquid and acts as a seal between the suction and discharge ports.

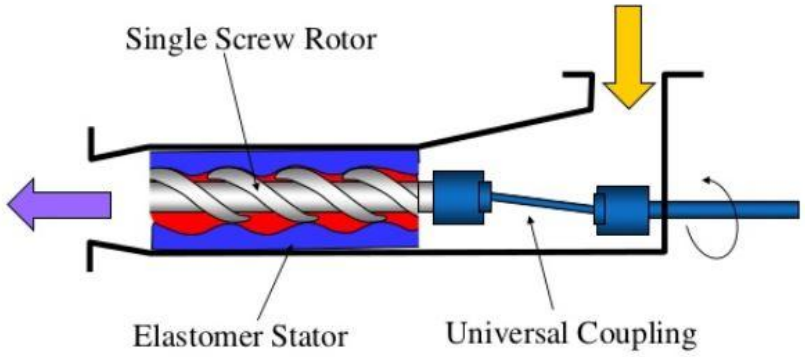
3. The pump head is now nearly flooded, just prior to forcing the liquid out of the discharge port. Intermeshing gears of the idler and rotor form locked pockets for the liquid which assures volume control.

4. Rotor and idler teeth mesh completely to form a seal equidistant from the discharge and suction ports. This seal forces the liquid out of the discharge port.

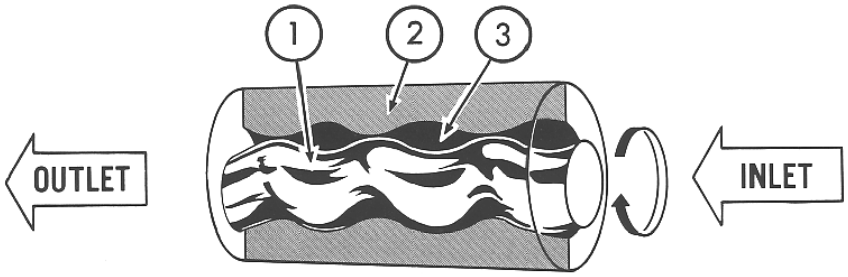
SINGLE SCREW PUMPS

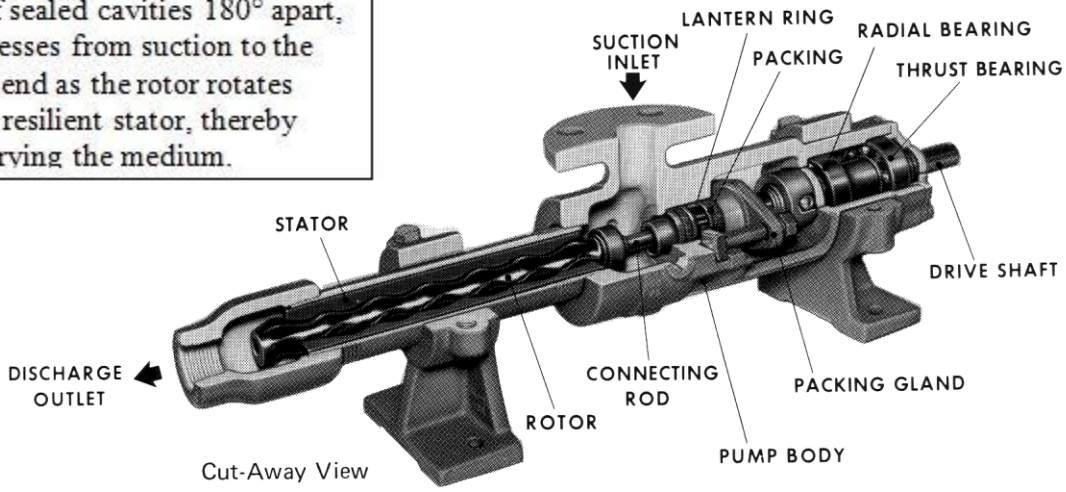
Single Screw

A single **screw pump** is a positive-displacement pump move fluids or solids along the screws axis. In its simplest form (the Archimedes' screw pump), The pump design consists of a single helical external threaded metallic rotor that rotates eccentrically inside a double helical internal threaded elastomeric stator of the same minor diameter and twice the pitch length.
Interference fit between the metallic rotor and the elastomeric stator form a series of sealed cavities 180° apart, that progresses from suction to the discharge end as the rotor rotates inside the resilient stator, thereby gently carrying the medium.



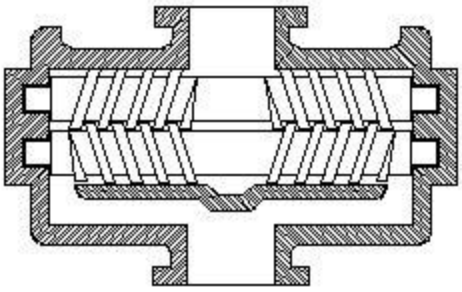
Liquid enters the Suction Inlet either under pressure or by gravity and as the ROTOR (1) turns within the flexible rubber STATOR (2) forming tightly sealed cavities (3) which moves the Liquid toward the Discharge Outlet. Pumping action starts the instant the ROTOR turns. Liquid acts as the lubricant between the pumping elements.

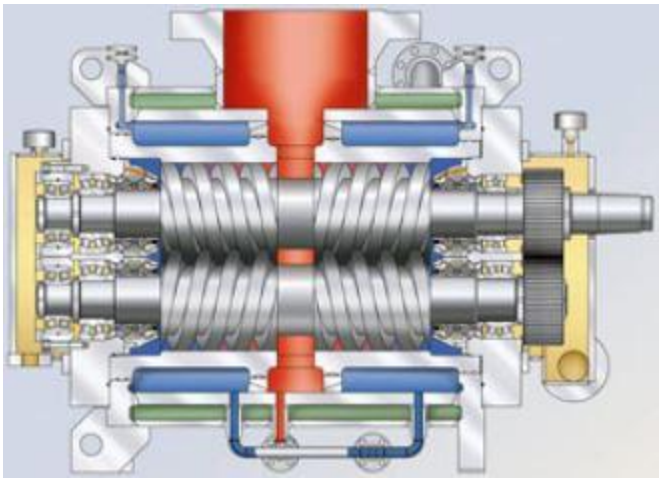




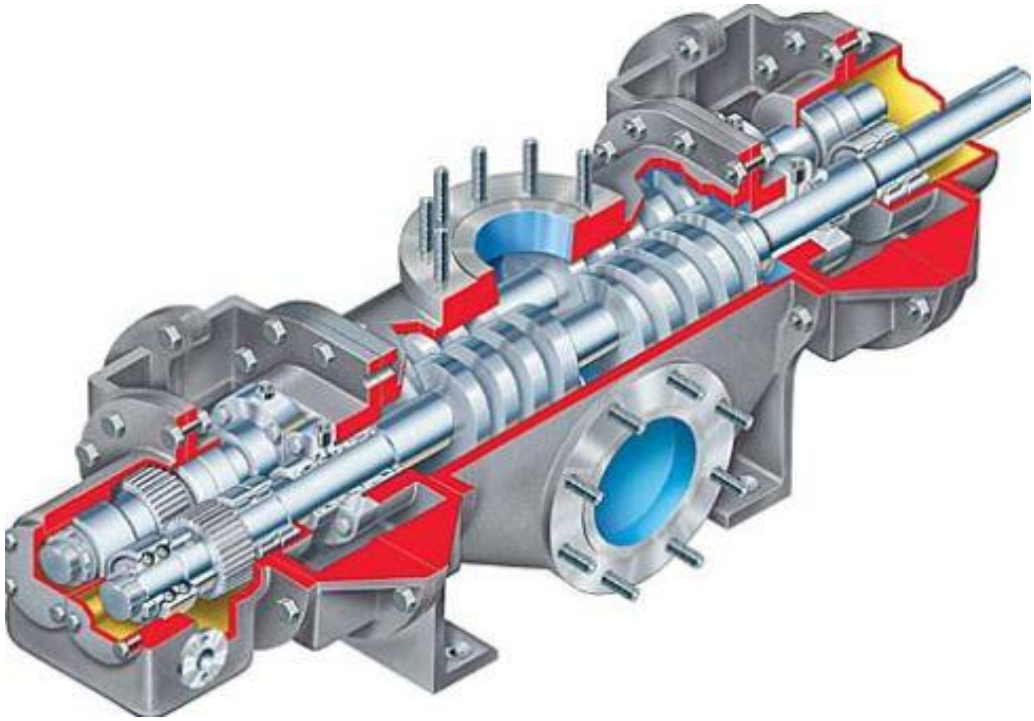
Cut-Away View

TWIN-SCREW PUMPS





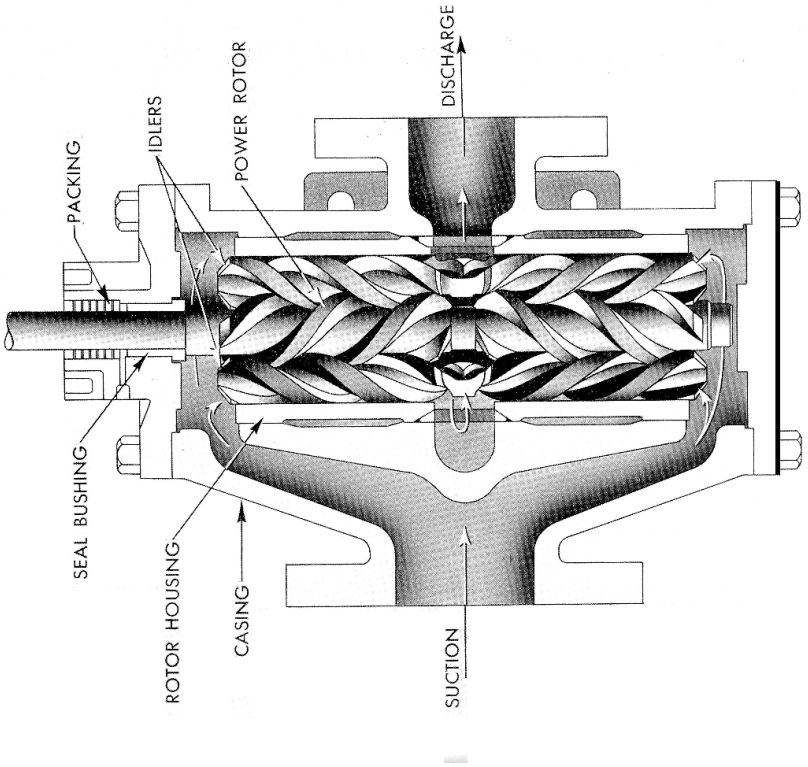
This pump operates with a drive screw intermeshing with a driven screw which transfers torque from one to the other. The screws are surrounded by a pump housing made of ferrous material. The screw geometry and the housing form the pumping chamber. Rotation, screw diameter, and screw pitch define the pump‘s flow rate. The product lubricates the internals. Four special bushings keep the screws aligned. The axial force resulting from the pumping motion is practically zero due to the pump’s hydraulic balancing.



These are good pumps for moving heavy crude oils heated by steam.

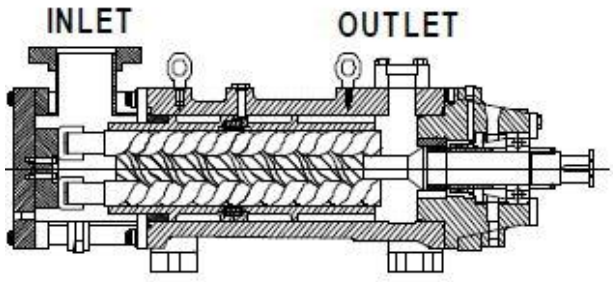
THREE SCREW PUMPS

Three screw pumps will generally have only one mechanical shaft seal and one, or perhaps two, bearings that locate the shaft axially. Internal hydraulic balance is such that axial and radial hydraulic forces are opposed and cancel each other. Bearing loads are thus very low.

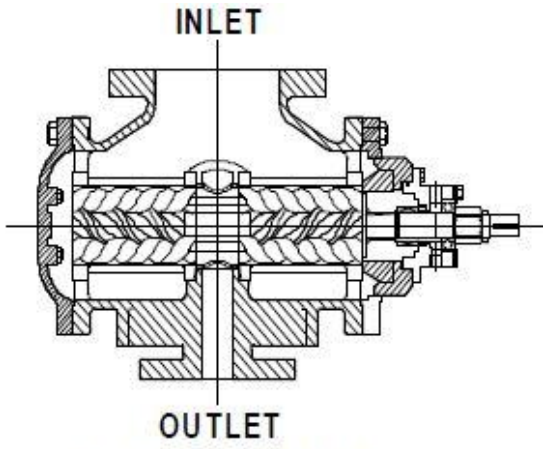


The center screw, called the power rotor, performs all the pumping. The meshed outside screws, called idler rotors, cause each liquid-holding chamber to be separated from the adjacent one except for running clearances. This effectively allows staging of the pump pressure rise

High pressure pumps may have as many as 12 stages while low pressure pumps may have only two or three. Because the center screw is performing all the pumping work, the drive torque transferred to the idler rotors is only that necessary to overcome viscous drag of the cylindrical rotor spinning within its liner clearance. Larger pumps being inherently more efficient than smaller pumps, a fact that applies to most rotating machinery.



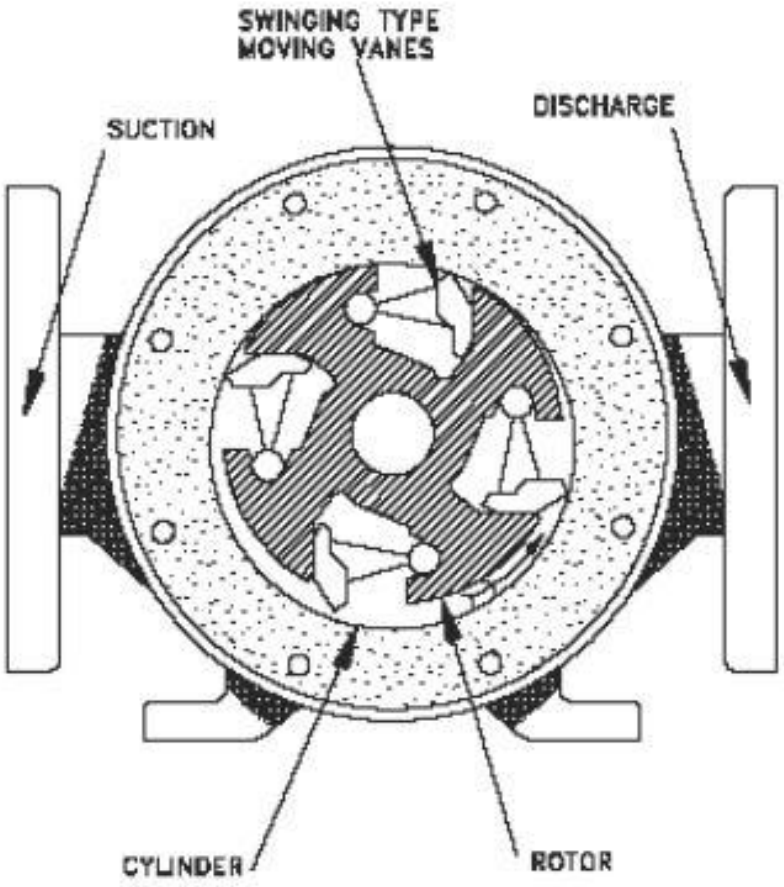
SINGLE SUCTION



DOUBLE SUCTION

SWINGING-VANE PUMPS

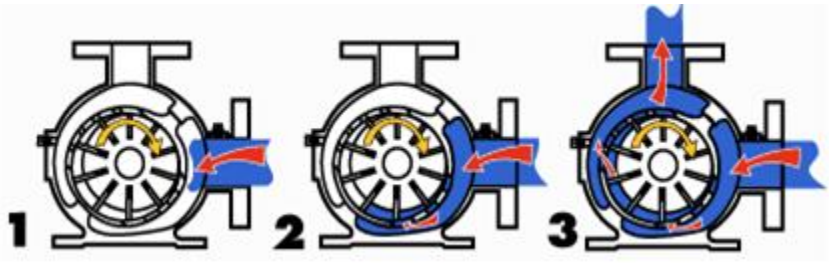
The swinging vane pump is an example of a type of rotary positive displacement pump. The pump consists of a cylindrically bored housing with a suction inlet on one side and a discharge outlet on the other. A cylindrically shaped rotor with a diameter smaller than the cylinder is driven about an axis placed above the centerline of the cylinder. The clearance between rotor and cylinder is small at the top but increases at the bottom. The rotor carries vanes that move in and out as it rotates to maintain sealed spaces between the rotor and the cylinder wall. The vanes trap liquid or gas on the suction side and carry it to the discharge side, where contraction of the space expels it through the discharge line. The vanes may swing on pivots, or they may slide in slots in the rotor.

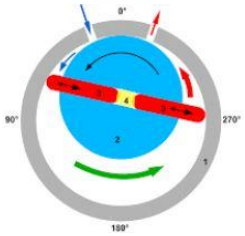


SLIDING-VANE PUMPS

While vane pumps can handle moderate viscosity liquids, they excel at handling low viscosity liquids such as LP gas (propane), ammonia, solvents, alcohol, fuel oils, gasoline, and refrigerants. Vane pumps have no internal metal-to-metal contact and self-compensate for wear, enabling them to maintain peak performance on these non-lubricating liquids. Vane pumps are noted for their dry priming, ease of maintenance, and good suction characteristics over the life of the pump. Moreover, vanes can usually handle fluid temperatures from -25 F to 500 F and differential pressures to 200 PSI. Sliding vane pumps can run dry for short periods of time and handle small amounts of vapor.

Despite the different configurations, most vane pumps operate under the same general principle described below.





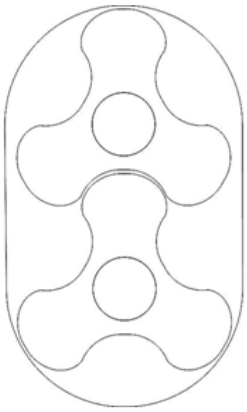
1. A slotted rotor is eccentrically supported in a cycloidal cam. The rotor is located close to the wall of the cam so a crescent-shaped cavity is formed. The rotor is sealed into the cam by two sideplates. Vanes or blades fit within the slots of the impeller. As the rotor rotates (*yellow arrow*) and fluid enters the pump, centrifugal force, hydraulic pressure, and/or pushrods push the vanes to the walls of the housing. The tight seal among the vanes, rotor, cam, and sideplate is the key to the good suction characteristics common to the vane pumping principle.

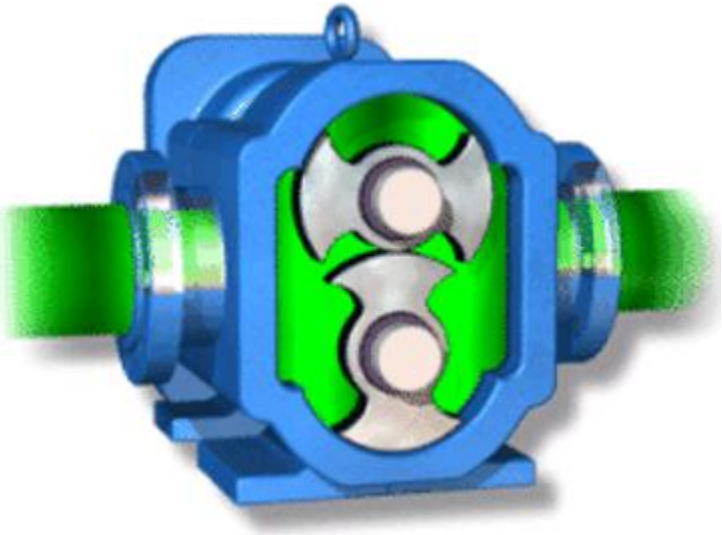
2. The housing and cam force fluid into the pumping chamber through holes in the cam (*small red arrow on the bottom of the pump*). Fluid enters the pockets created by the vanes, rotor, cam, and sideplate.

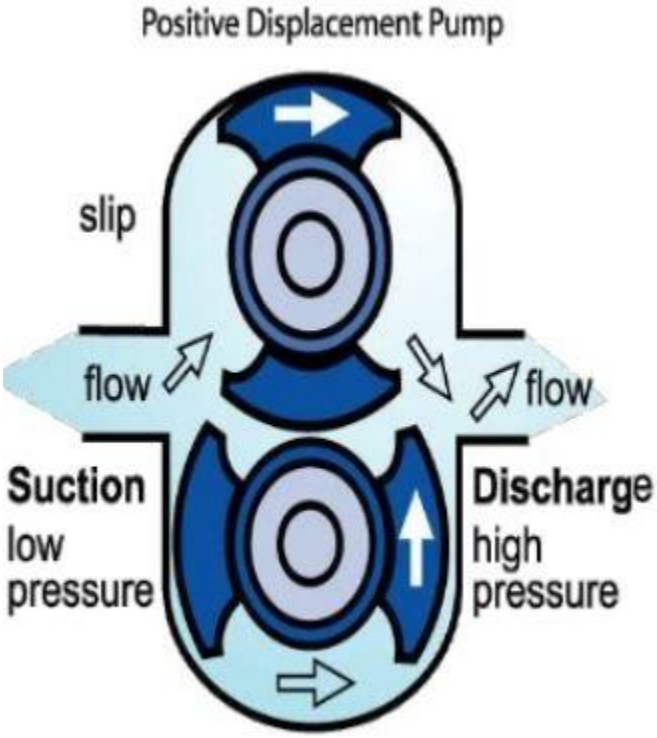
3. As the rotor continues around, the vanes sweep the fluid to the opposite side of the crescent where it is squeezed through discharge holes of the cam as the vane approaches the point of the crescent (*small red arrow on the side of the pump*). Fluid then exits the discharge port.

The rotor carries vanes (which move in and out as the rotor rotates) to maintain sealed spaces between the rotor and the cylinder wall. The vanes trap liquid on the suction side and carry it to the discharge side, where contraction of the space expels liquid through the discharge line. The vanes slide on slots in the rotor. Vane pumps are used for lube oil service and transfer and, in general, for handling lighter viscous liquids.

TWO-LOBE and THREE LOBE PUMPS







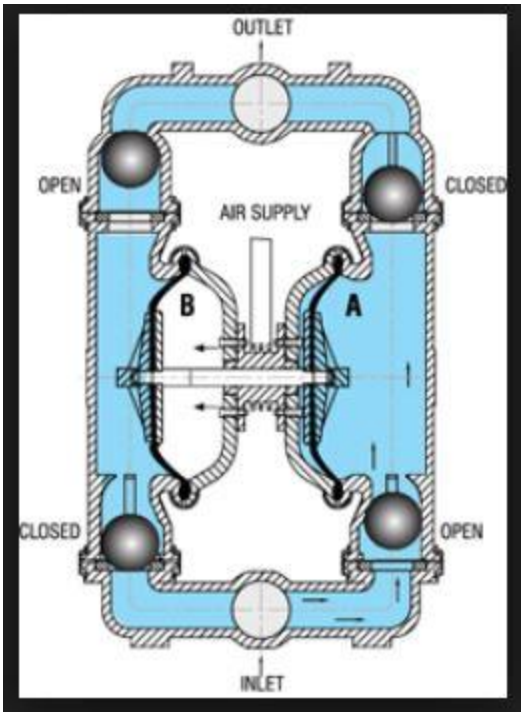
Lobe pumps are similar to external gear pumps in operation in that fluid flows around the interior of the casing. Unlike external gear pumps, however, the lobes do not make contact. Lobe contact is prevented by external timing gears located in the gearbox. Pump shaft support bearings are located in the gearbox, and since the bearings are out of the pumped liquid, pressure is limited by bearing location and shaft deflection.

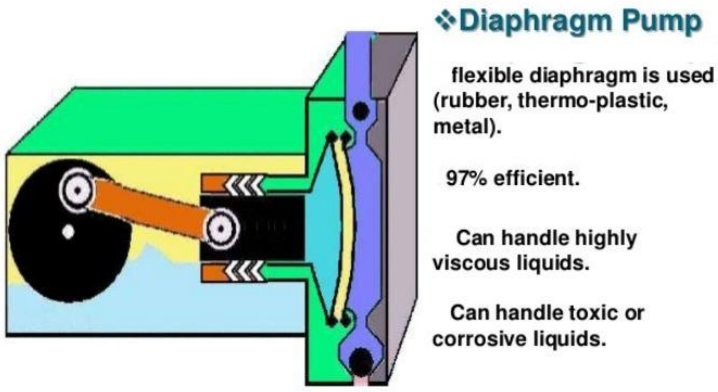
1. As the lobes come out of mesh, they create expanding volume on the inlet side of the pump. Liquid flows into the cavity and is trapped by the lobes as they rotate.

2. Liquid travels around the interior of the casing in the pockets between the lobes and the casing—it does not pass between the lobes.

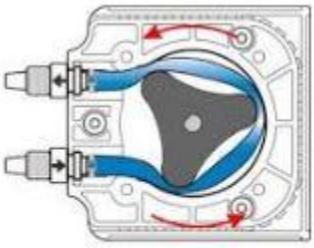
3. Finally, the meshing of the lobes forces liquid through the outlet port under pressure.

DIAPHRAGM PUMPS




❖Diaphragm Pump
flexible diaphragm is used (rubber, thermo-plastic, metal).
97% efficient.
Can handle highly viscous liquids.
Can handle toxic or corrosive liquids.

Diaphragm Pump (single acting)



Peristaltic Pump

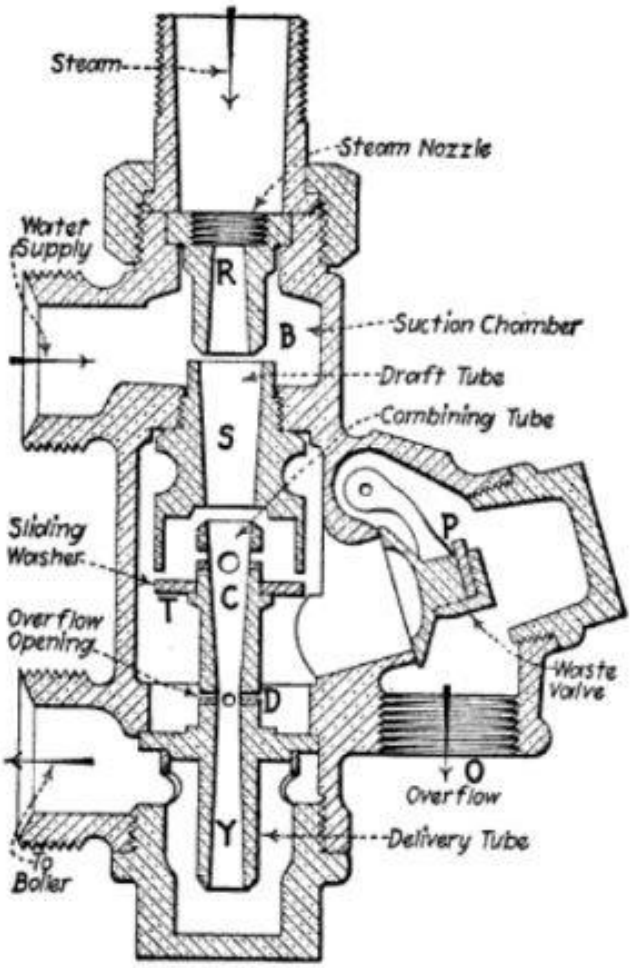
Progressing Squeezing Action
(no check valves)

Diaphragm pumps are also classified as positive displacement pumps because the diaphragm acts as a limited displacement piston. The pump will function when a diaphragm is forced into reciprocating motion by mechanical linkage, compressed air, or fluid from a pulsating, external source. The pump construction eliminates any contact between the liquid being pumped and the source of energy. This eliminates the possibility of leakage, which is important when handling toxic or very expensive liquids. Disadvantages include limited head and capacity range, and the necessity of check valves in the suction and discharge nozzles. The small pumps are commonly used to feed chemicals into the boiler.

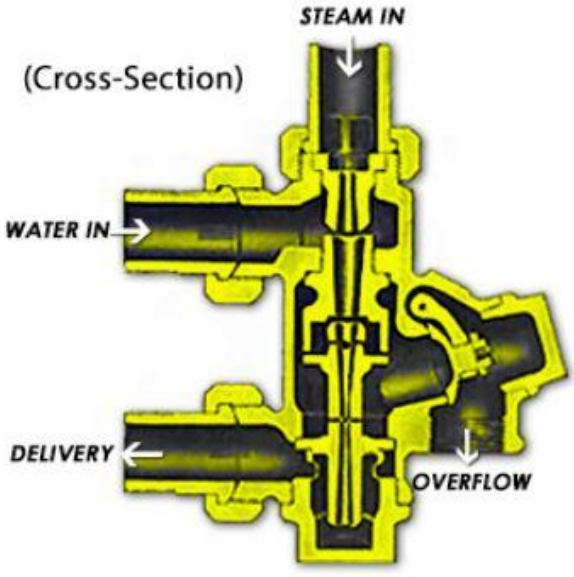
INJECTORS

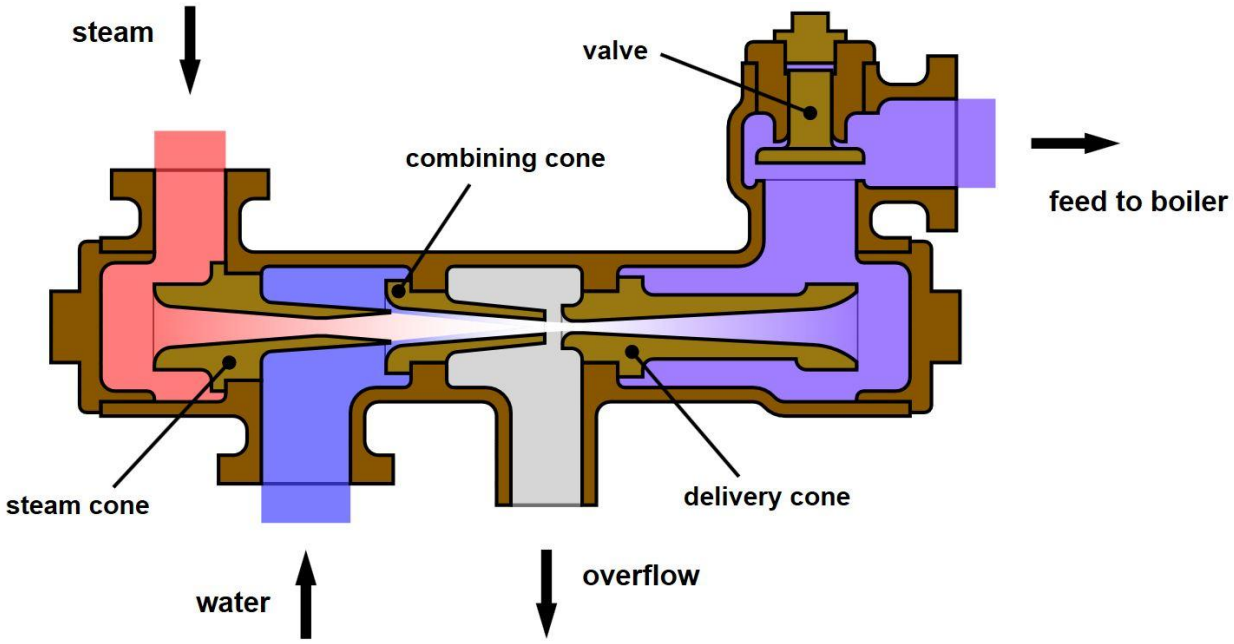
How an automatic injector works is indicated by the illustration which shows a section through a Penberthy Automatic Injector. This is a single tube, re-starting, lifting-type injector that operates on Bernoulli's principle.

Steam enters at the top, and, expanding in the steam nozzle, R, rushes through the draft-tube, S, carrying with it enough entrained air to create a partial vacuum in suction chamber, B. Unable to discharge against the boiler pressure, this steam escapes through the large opening above the sliding washer, T, and through the overflow opening, D, via P and O to the atmosphere. The partial vacuum in B has already lifted water into it, and this water has condensed part of the steam. As more and more of the steam condenses, the jet becomes more compact and finally becomes sufficiently small to pass through the least diameter of the combining tube, C. Thence it passes through the delivery tube, Y, and the check valve to the boiler. The swiftly-moving jet of water-and-condensed-steam creates a partial vacuum in tube C. This draws the loose washer, T, up against its seat. Thereby is prevented any inrush of air which would scatter the jet. The closing of T also prevents any loss of feed water through it. If the steam or water supply becomes interrupted, the jet is destroyed and the vacuum above T is lost. This allows T to drop down to its original position. Hence, upon the resumption of the steam or water supply, the operation just described is repeated.



"Penberthy" Single-Tube Automatic Injector.





An injector is a steam operated device that can pick up cold water and give it enough force to enter the boiler while heating it up at the same time. The injector can lift and force a jet of water many times the weight of the original jet of steam. The injector has no moving parts except for the overflow flapper that is pulled shut when the steam blowing past a venturi creates a vacuum.

Important facts to remember about the injector are:

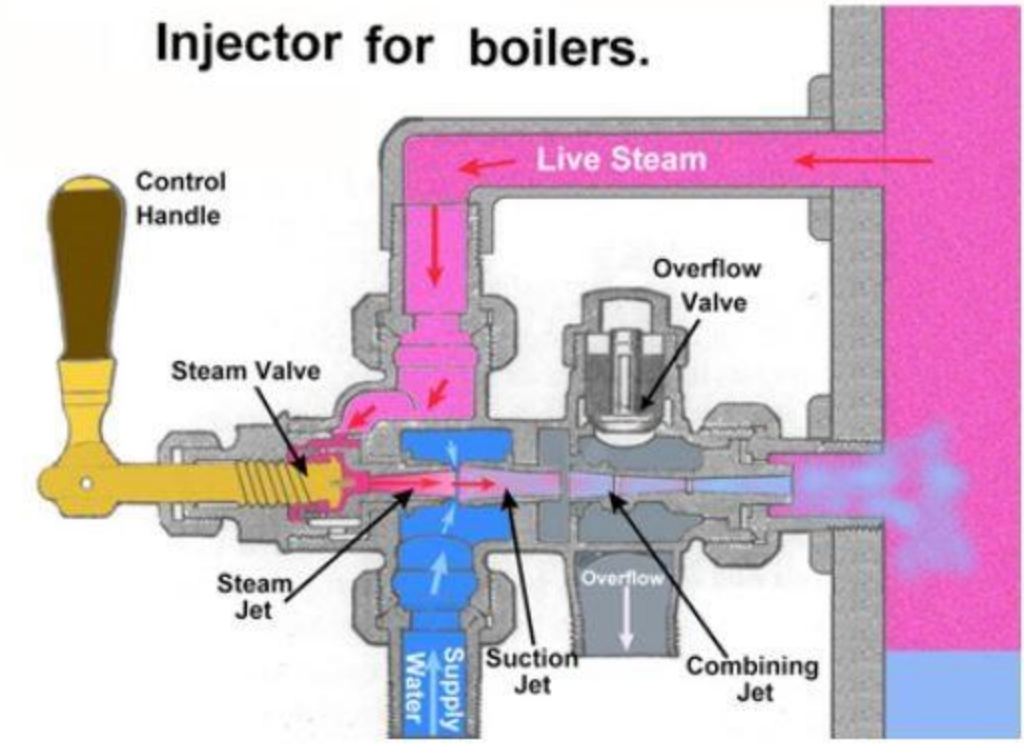
1. Hot water is fed to the boiler without pre-heating the water.

2. The injector is not dependent upon an outside source of power to operate. It uses boiler pressure to force the make-up water back into the boiler. If the feedwater pump fails, the injector can be used to keep the boiler on line until the pump is fixed. This can be a lifesaver in an emergency situation.

3. The injector is very compact, has no mechanically operated parts and requires no foundation or floor space.

4. The first cost and the maintenance costs are low.

5. Because of its simplicity, the injector is very dependable as long as the venturis are kept free from scale.



6. Venturis are kept clean by dropping them into a mixture of 10 parts water to one part muriatic acid. The nozzles will bubble until all the scale is removed. Coca Cola will also work.

7. Injectors have a thermal efficiency of almost 100% and a mechanical efficiency of 1 to 2%.

8. An automatic injector will restart itself on an interruption of water supply. A positive injector must be manually restarted on an interruption of steam or water supply. Positive injectors are obsolete.

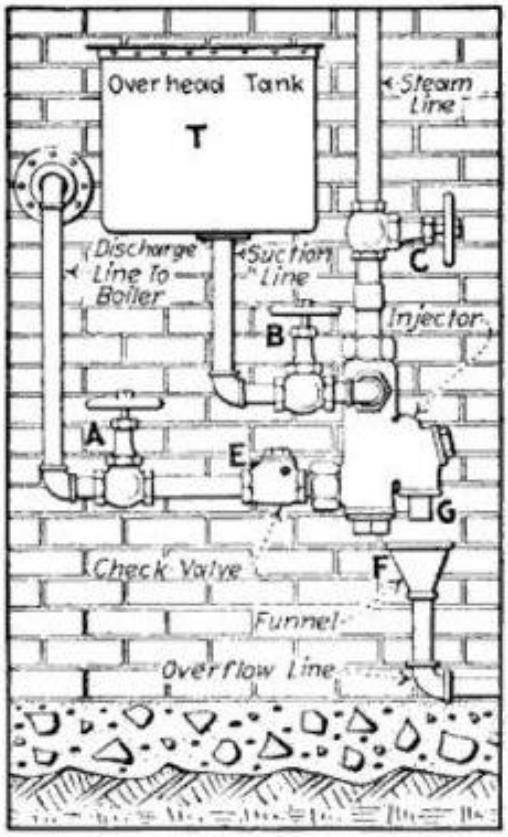
9. The injector must have a cool water supply to operate correctly, 150 degrees or less.

10. The vacuum created in the injector is from 14" to 24" of mercury.

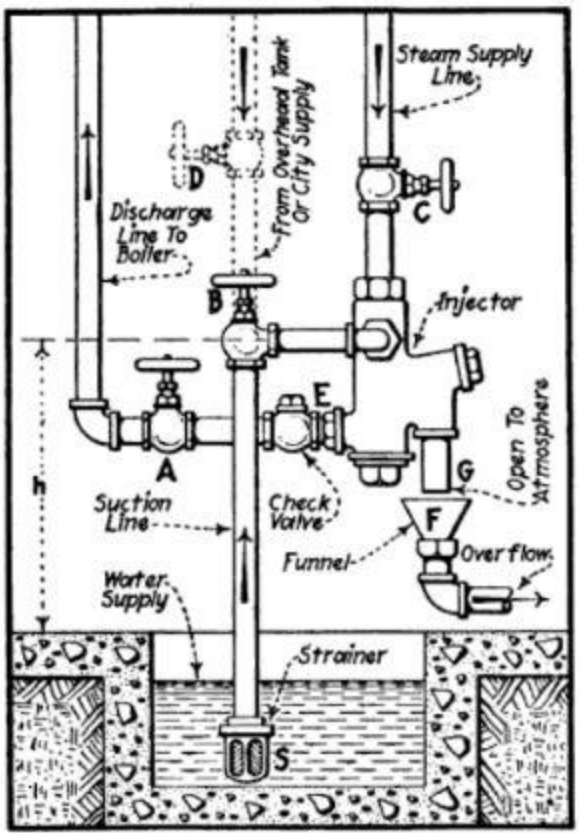
11.When the source of water s below the injector, the vacuum allows atmospheric pressure to push the water into the injector.

The Advantages of an Injector are:

(1) Simplicity.
(2) Compactness.
(3) Low first-cost.
(4) High temperature of feed-water delivered.
(5) Ease of operation.
(6) Low cost of upkeep and repairs.
(7) High thermal efficiency, about 99 percent of energy put into it is utilized. The absence of any moving parts is responsible for most of these advantages.



Injector Fed From Overhead Tank.



Piping Of An Injector.

STARTING AN INJECTOR WITH WATER PRESSURE TO THE INJECTOR

1. Drain the condensate from the steam line from the boiler to the injector.

2. Open the valves leading from the injector to the boiler.

3. Open the water inlet valve wide, water will pour out the overflow

4. Slowly open the steam valve wide, the overflow will snap shut and you will be feeding water to the boiler.

5. If the steam or water still comes out the overflow, throttle back the water.

A lifting injector will require opening the steam first until the air can be eliminated and water drawn up into the injector.

STOPPING AN INJECTOR

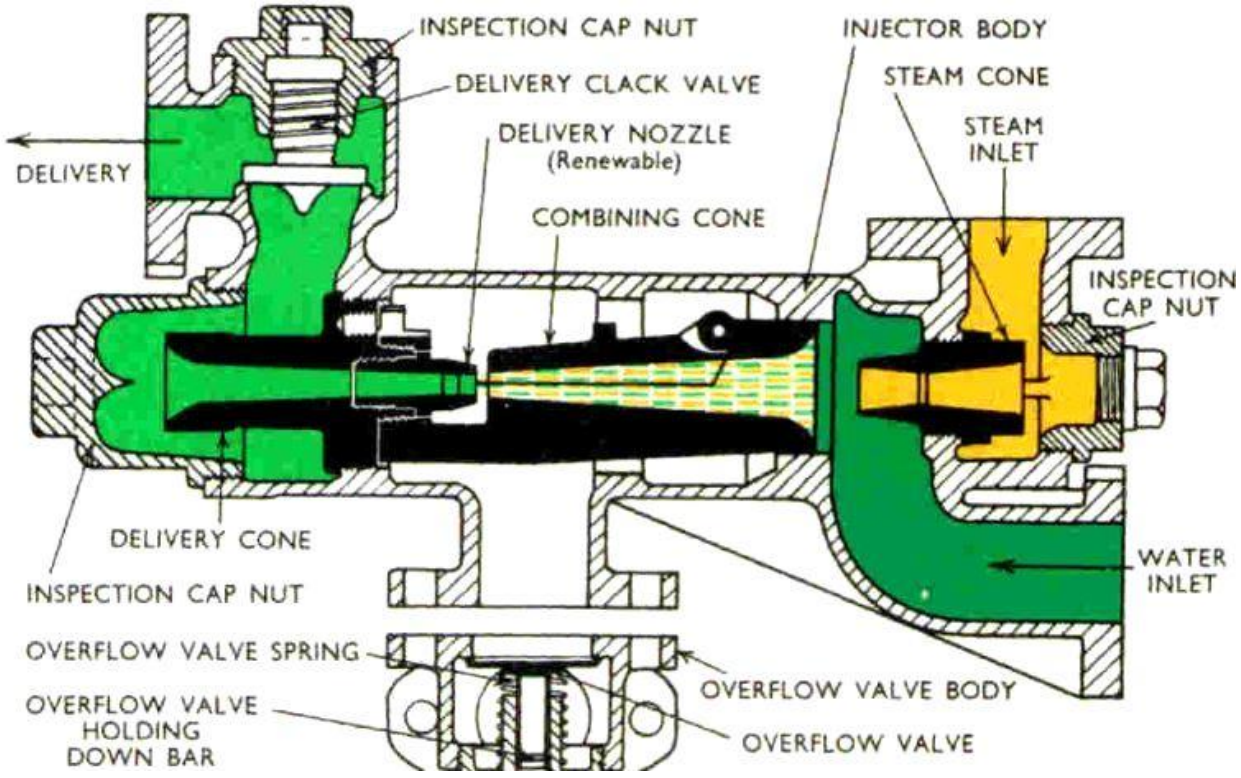
1. Close the Steam valve.

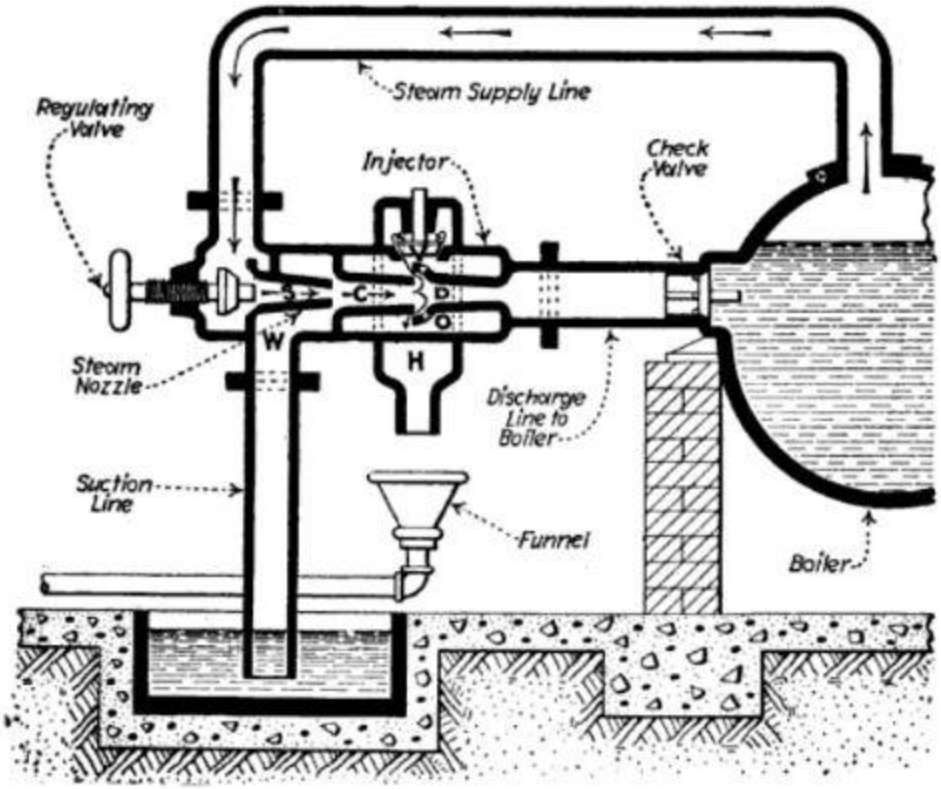
2. Close the water valve.

3. Close the discharge valve from the injector to the boiler.

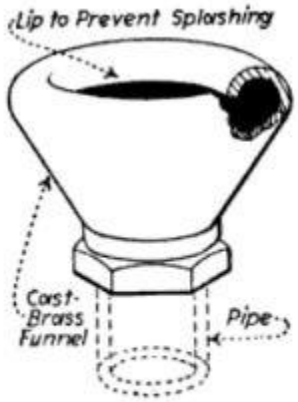
REASONS WHY AN INJECTOR WILL NOT OPERATE

1. The discharge line to the boiler or any other valves to and from the injector are closed.
2. There are leaks in the suction line.
3. The water is too hot.
4. The steam pressure is too low.
5. The suction strainer is clogged.
6. The nozzles are clogged with lime deposits from the water.
7. The overflow valve is stuck open or is leaking around the seat.
8. The steam supply is too wet.
9. The end of the suction line is not below the level of the water.
10. A rubber hose was used for the suction line and the line collapsed from the vacuum.

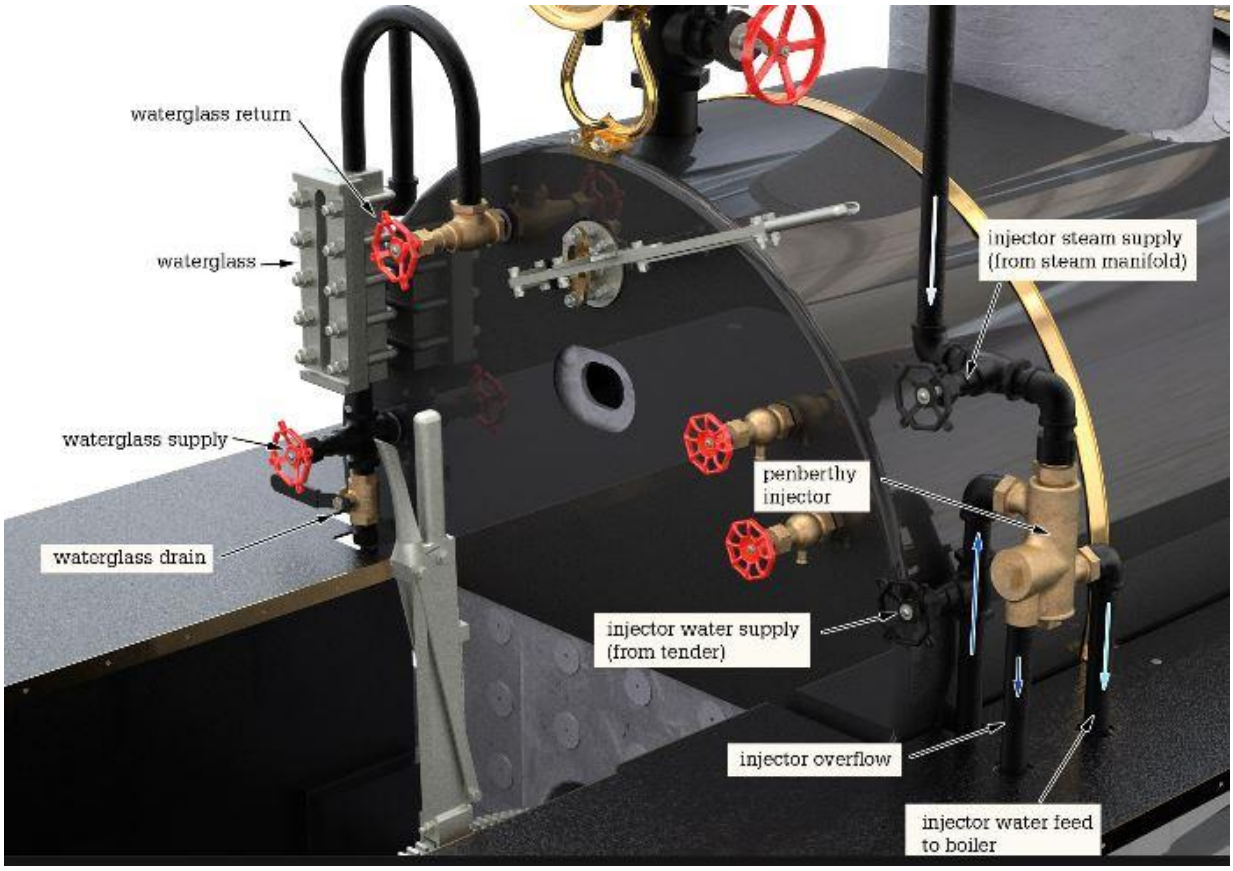




Illustrating The Principle Of The Injector.

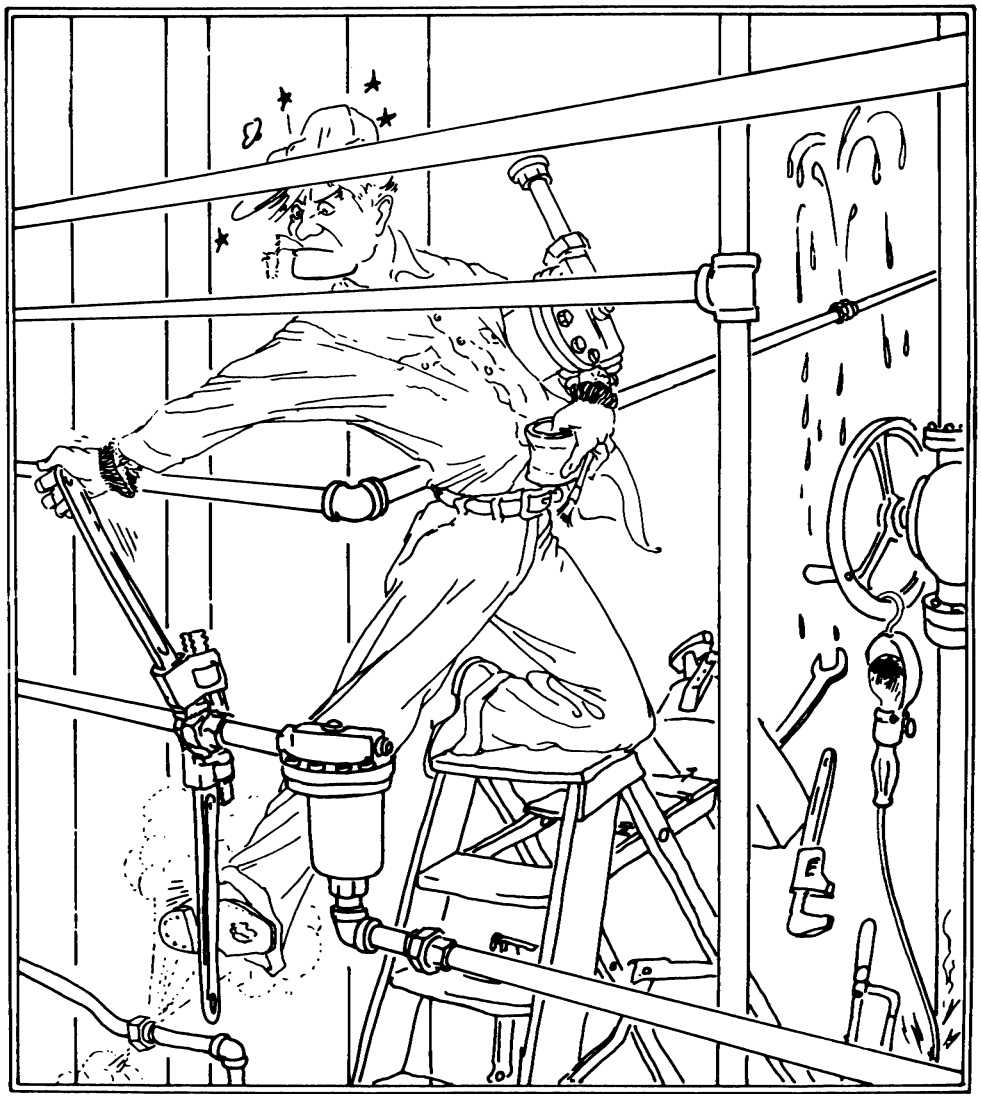


"Non-Splash" Funnel For Injector Overflow Pipe.



Chapter 12 Questions

1. How large should a boiler feed pump be?
2. A building has water piping 40 feet up from floor level. No extra pressure is in the pipe. What is the pressure in the gauge at the bottom of the pipe?
3. How does a centrifugal pump operate?
4. Why are wearing rings used?
5. How can you get water into a centrifugal pump to start it?
6. Why are open feedwater heaters located above the pump?
7. How do you start a centrifugal pump?
8. What is cavitation?
9. How does a regenerative turbine pump work?
10. What valve materials are used for which pressure ranges for reciprocating pumps?
11. Why does a duplex pump have lost motion?
12. What is the stroke of a 3 X 2 X 3 duplex pump?
13. How do you start a duplex pump?
14. How do you start an injector?
15. How do you shut down an injector?



Boiler Operator Changing Steam Traps (Courtesy Barnes and Jones)

Chapter 13

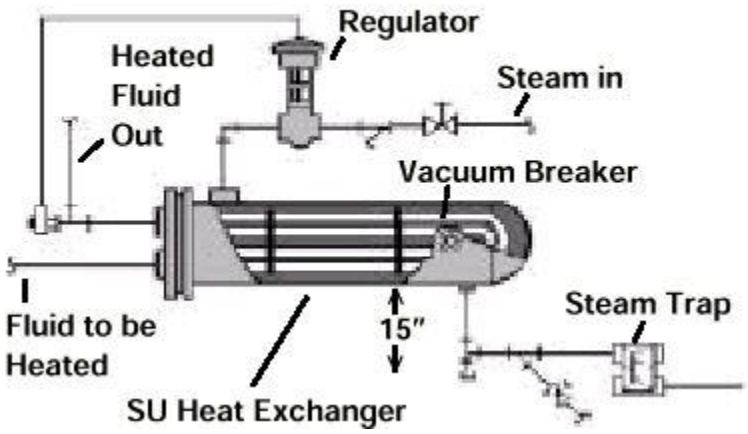
STEAM TRAPS

When steam has done useful work and given up its heat energy, or when it has otherwise cooled sufficiently to condense from steam back into water, the water that is formed must be removed. If the water were allowed to accumulate in the steam line, water hammer could result.

Water Hammer caused an explosion that blew apart a steam line in New York in 2007, killing one and injuring 45 people

Example of piping damaged by water hammer

Water hammer occurs when the flow of steam in a pipe pulls along water lying in the pipe until the pipe reaches an elbow, or other restriction. The water slams into the restriction with a loud bang and shakes the piping. Water hammer can cause the pipe to rupture and gaskets to fail. The water may come from condensation due to the lack of insulation on the steam lines.



Water accumulating on the steam side of heat exchangers will prevent the heat exchanger from operating properly. In order to remove the condensate as soon as it is formed, steam traps are used. Steam traps perform four useful functions:

1. They separate condensate from the steam.

2. Steam traps allow the condensate to flow back to a condensate tank or be dumped to the atmosphere.

3. They prevent steam from blowing back to the condensate tank or atmosphere, which would waste fuel.

4. Steam traps can vent air from the steam pipe.

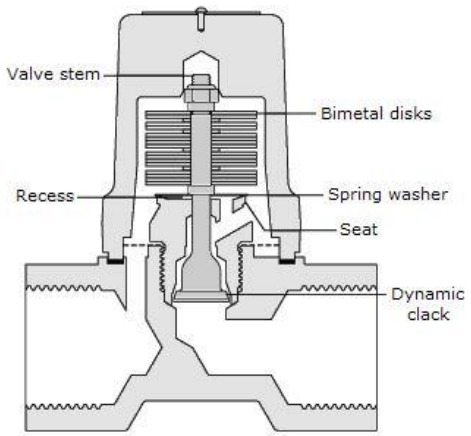
A steam trap's useful life ranges from 1 to 5 years. If a steam trap fails open, large amounts of steam blow through and fuel dollars are wasted. If a steam trap fails closed, condensate will start to back up into the steam line.

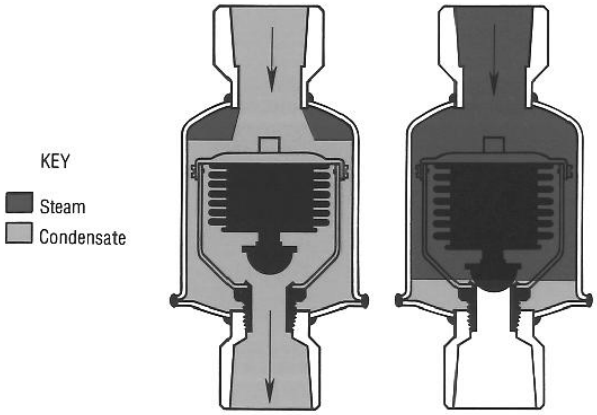
There are seven basic types of steam traps, the first six are referred to as non-return traps because the condensate is not returned directly to the boiler. The condensate is usually sent to a condensate tank before being pumped back to the boiler. The return trap is a boiler feeding device that uses the weight of the condensate and its location to return the condensate directly to the boiler. The seven basic steam traps are:

1. Thermostatic Trap
2. Bucket Trap
3. Inverted Bucket Trap
4. Ball Float Trap
5. Impulse Trap
6. Orifice Trap
7. Return Trap

THERMOSTATIC TRAP

The thermostatic trap operates on the principle that condensate will cool down to a temperature less than that of the steam from which it was formed. The thermostatic trap consists of a sealed bronze bellows partially filled with a volatile fluid. Attached to the end of the bellows is a steel cone that fits into a seat in the valve body. As the steam surrounds the bellows, the volatile fluid inside heats up and expands the bellows, driving the cone into its seat and closing off the outlet of the trap. As condensate forms around the bellows and cools the volatile fluid inside, the bellows contracts and opens the outlet from the trap, allowing the condensate to drain from the trap.





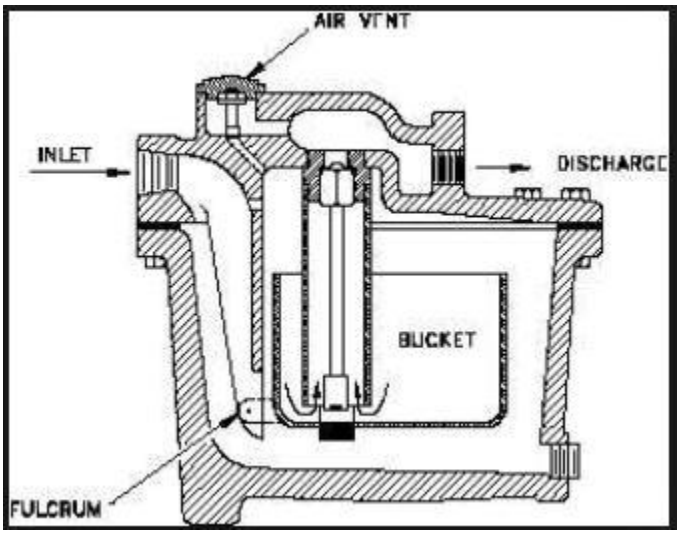
Important points to remember about the thermostatic trap are:

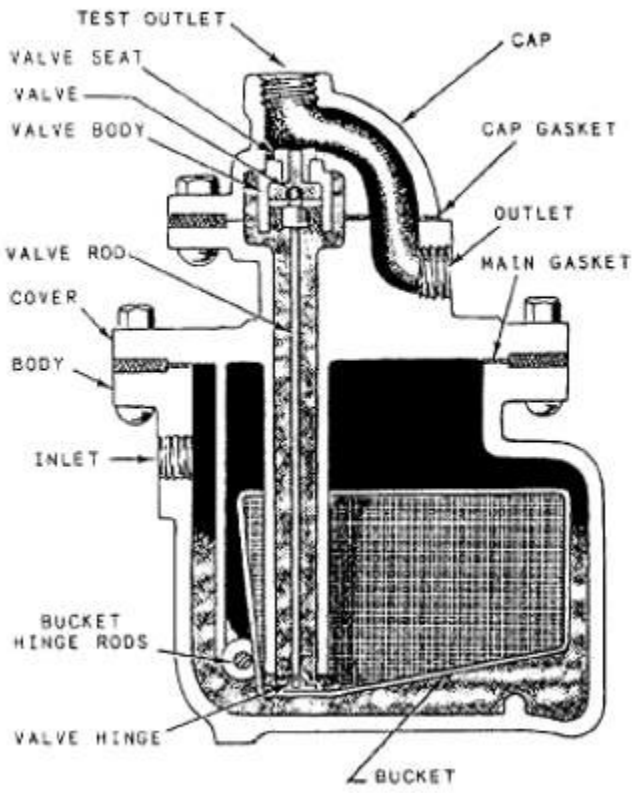
1. This type of trap is commonly found on steam radiators used for space heating due to its compact size, low cost and ease of replacement. The bellows and seat can usually be replaced without removing the trap from the piping.
2. Never open the trap until it has cooled or the bellows may be damaged from overexpansion.
3. The thermostatic trap should not be used where the temperature around the trap varies greatly or it may not operate properly.
4. The thermostatic trap is subject to damage by freezing.
5. Thermostatic traps can be damaged by water hammer.

BUCKET TRAP

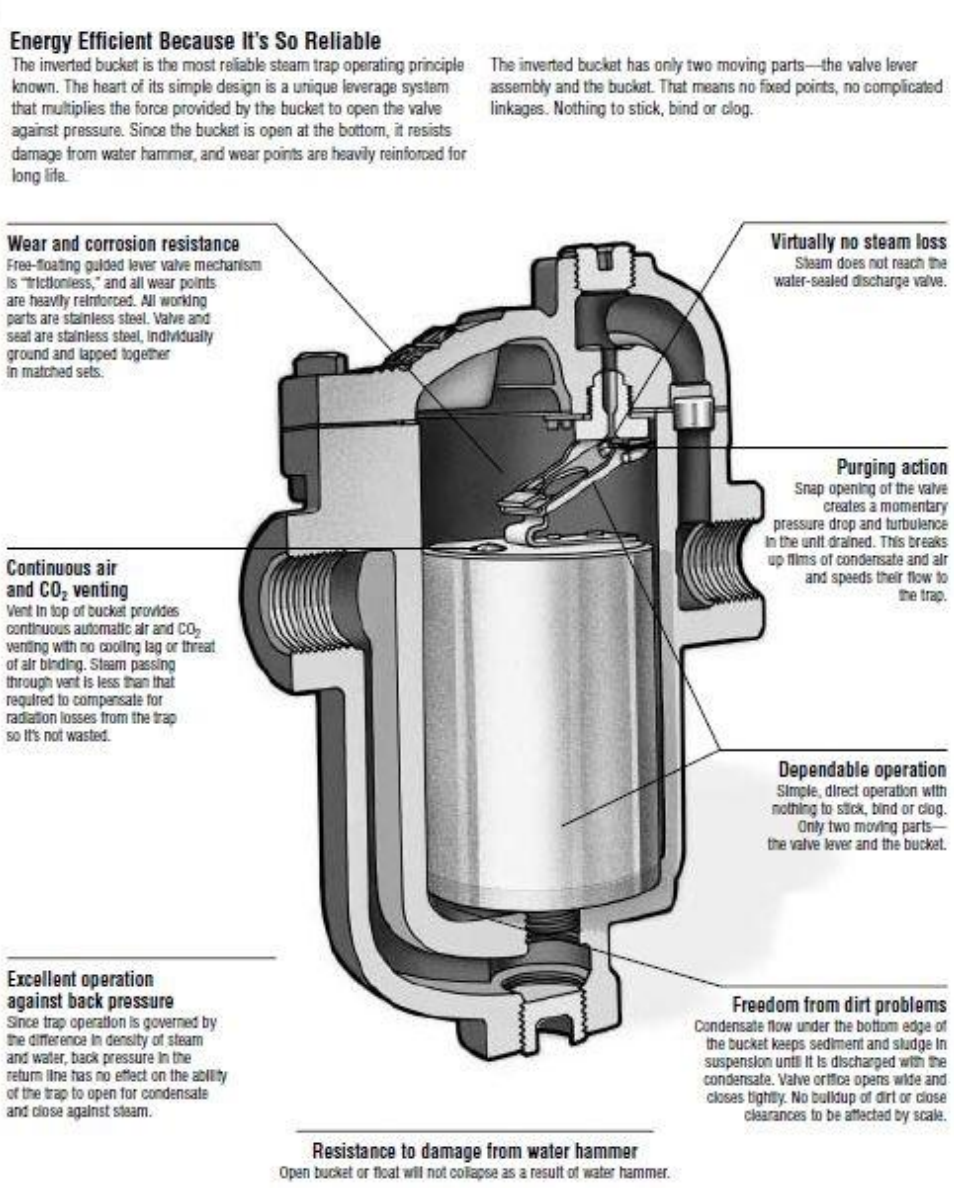
The bucket trap operates on the principle that a metal bucket will float on the top of water when it is empty and will sink when it is full. The inlet to the bucket trap is arranged so that there is always condensate under the bucket, keeping it afloat. The floating bucket is attached to the discharge needle holding the outlet from the trap closed. As more condensate comes into the trap, it rises along the sides of the bucket until it gets high enough to spill into the bucket. As the bucket fills with water it loses its buoyancy and starts to sink. As the bucket sinks, the discharge needle moves with the bucket away from its seat and the outlet to the discharge line is opened. The discharge needle is surrounded by a pipe open at the bottom and the steam pressure in the trap forces the water up the pipe and out the trap. Once enough water has been forced out of the bucket, the bucket again floats and the discharge needle again closes the outlet from the trap. The disadvantage of the bucket trap is that dirt can build up in the bottom of the bucket, weighing the bucket down so that it will not float.

The operation of the bucket-type steam trap, is controlled by the condensate level in the trap body. The bucket valve is connected to the bucket in such a way that the valve closes as the bucket rises. As condensate continues to flow into the trap body, the valve remains closed until the bucket is full. When the bucket is full, it sinks and thus opens the valve. The valve remains open until enough condensate has blown out to allow the bucket to float, thus closing the valve.





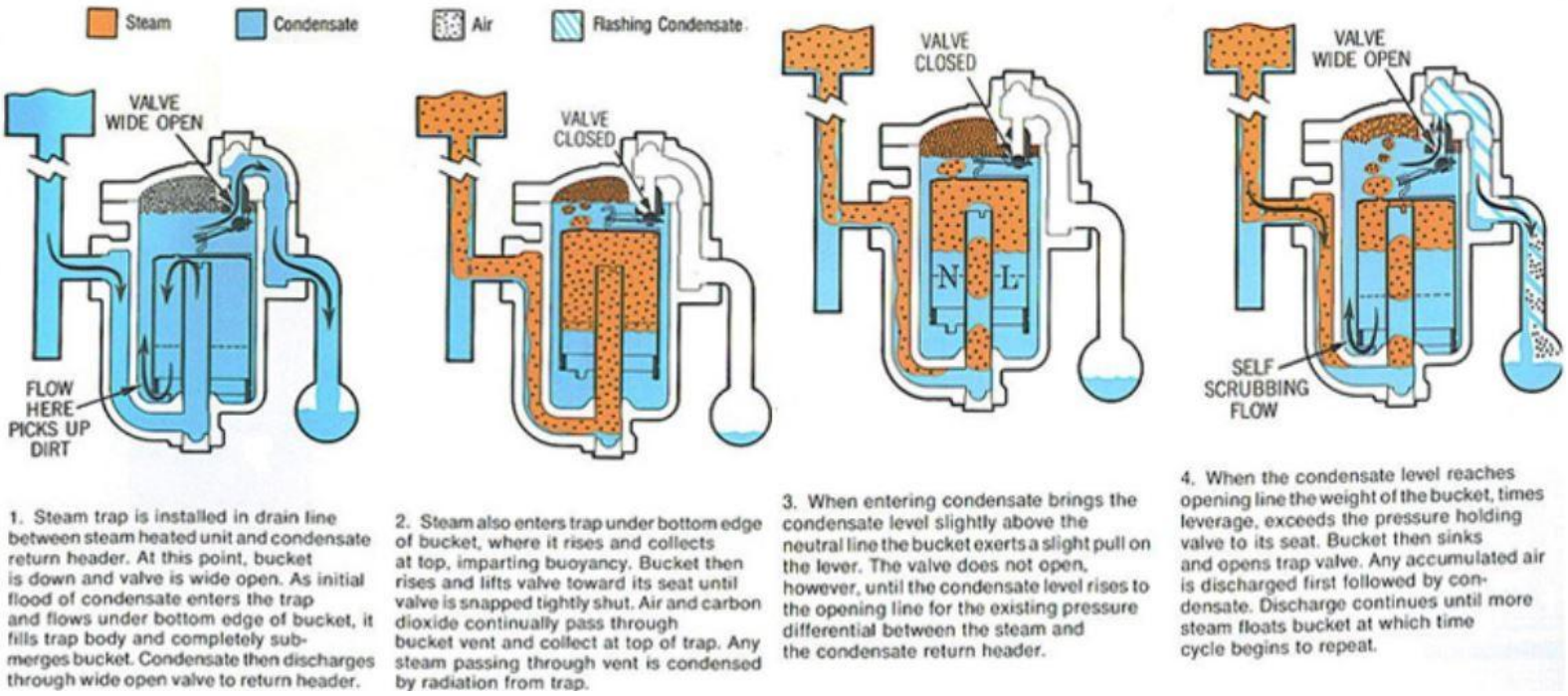
INVERTED BUCKET TRAP


Energy Efficient Because It's So Reliable
The inverted bucket is the most reliable steam trap operating principle known. The heart of its simple design is a unique leverage system that multiplies the force provided by the bucket to open the valve against pressure. Since the bucket is open at the bottom, it resists damage from water hammer, and wear points are heavily reinforced for long life.
The inverted bucket has only two moving parts—the valve lever assembly and the bucket. That means no fixed points, no complicated linkages. Nothing to stick, bind or clog.
Wear and corrosion resistance
Free-floating guided lever valve mechanism is "frictionless," and all wear points are heavily reinforced. All working parts are stainless steel. Valve and seat are stainless steel, individually ground and lapped together in matched sets.
Virtually no steam loss
Steam does not reach the water-sealed discharge valve.
Purging action
Snap opening of the valve creates a momentary pressure drop and turbulence in the unit drained. This breaks up films of condensate and air and speeds their flow to the trap.
Continuous air and CO_2 venting
Vent in top of bucket provides continuous automatic air and CO_2 venting with no cooling lag or threat of air binding. Steam passing through vent is less than that required to compensate for radiation losses from the trap so it's not wasted.
Dependable operation
Simple, direct operation with nothing to stick, bind or clog. Only two moving parts—the valve lever and the bucket.
Excellent operation against back pressure
Since trap operation is governed by the difference in density of steam and water, back pressure in the return line has no effect on the ability of the trap to open for condensate and close against steam.
Freedom from dirt problems
Condensate flow under the bottom edge of the bucket keeps sediment and sludge in suspension until it is discharged with the condensate. Valve orifice opens wide and closes tightly. No buildup of dirt or close clearances to be affected by scale.
Resistance to damage from water hammer
Open bucket or float will not collapse as a result of water hammer.

The inverted bucket trap operates on the principle that a metal bucket turned upside down in water will float. A small bleed hole in the top of the bucket allows air to pass through the top of the bucket. When steam enters underneath the bucket, it will float the bucket. Once the steam has condensed into water, the bucket is surrounded by water and the bucket will sink. As the bucket sinks, the discharge port from the bucket is opened and the condensate is allowed to leave.

1. This trap usually cycles open and closed but if the condensate flow is just right, it can continually discharge.

2. This trap must be primed to get it to work. Wrapping a wet rag around the trap will prime it or the valve on the discharge can be closed and the trap will be primed by waiting for the condensate to build before opening the valve again.

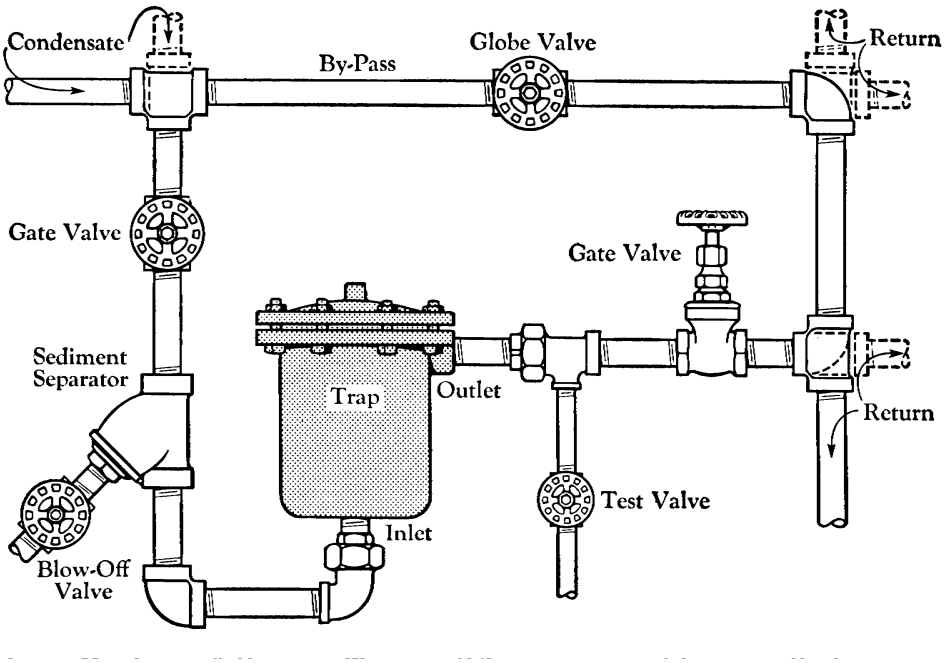


1. Steam trap is installed in drain line between steam heated unit and condensate return header. At this point, bucket is down and valve is wide open. As initial flood of condensate enters the trap and flows under bottom edge of bucket, it fills trap body and completely submerges bucket. Condensate then discharges through wide open valve to return header.

2. Steam also enters trap under bottom edge of bucket, where it rises and collects at top, imparting buoyancy. Bucket then rises and lifts valve toward its seat until valve is snapped tightly shut. Air and carbon dioxide continually pass through bucket vent and collect at top of trap. Any steam passing through vent is condensed by radiation from trap.

3. When entering condensate brings the condensate level slightly above the neutral line the bucket exerts a slight pull on the lever. The valve does not open, however, until the condensate level rises to the opening line for the existing pressure differential between the steam and the condensate return header.

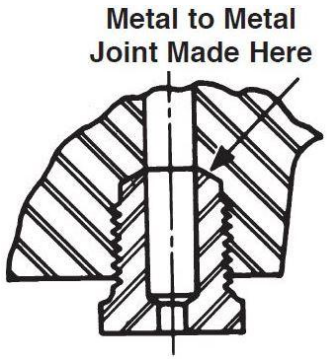
4. When the condensate level reaches opening line the weight of the bucket, times leverage, exceeds the pressure holding valve to its seat. Bucket then sinks and opens trap valve. Any accumulated air is discharged first followed by condensate. Discharge continues until more steam floats bucket at which time cycle begins to repeat.



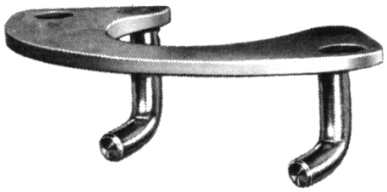
Courtesy Armstrong Machine Works

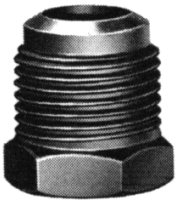
Proper piping of any steam trap should include all the fittings and valves you see here. There are two gate valves to isolate the trap. There is a throttling globe valve bypass to allow condensate to be relieved while the trap is being worked on. There are two unions around the trap to allow the trap to be removed and worked on at the bench. The strainer can be removed and cleaned because it is correctly placed within the isolation zone. After the trap is repaired and replaced, the outlet gate valve is opened wide. The trap must be primed by closing the globe valve and the inlet gate valve for a short time to allow condensate to build up and prime the trap. The globe valve will remain closed and the inlet gate valve is slowly opened. The test valve can used to make sure the job was done correctly.

ARMSTRONG INVERTED TRAP REPAIR

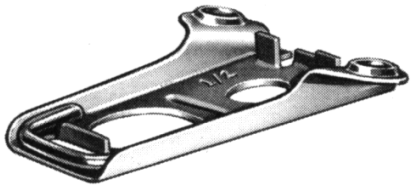


Valve Seat Installation. When installing valve seats in Armstrong traps, **do NOT use any pipe dope or lubricant of any kind on the seat threads.** The joint is made, not by the threads, but rather by the contact between the ground end of the valve seat and the beveled seating area at the bottom of the tapped hole. Make sure that this seating area is perfectly clean.


Guide Pin Assembly


Valve Seat

Guide pin assembly with post and notched lever employed in 15 psi No. 216 traps only.


Valve Lever

Valve

Valve Retainer

Replace Lever and Guide Pin Assembly. When new valve parts are used with an old lever, bucket travel, valve opening and trap capacity are reduced. With used and worn guide pins, the valve is not guided as closely to its seat. Poor guidance develops leaks quickly because the valve can strike the side of the seat instead of the center. When you install a new mechanism less bucket or a pressure change assembly, you make the trap as good as new.

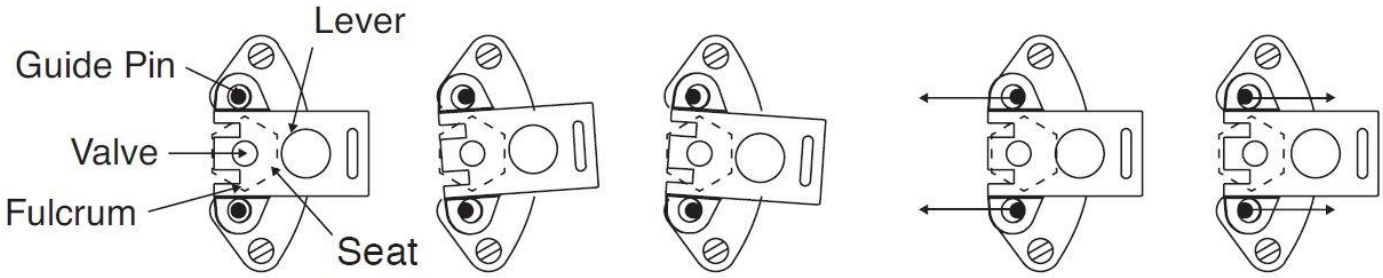
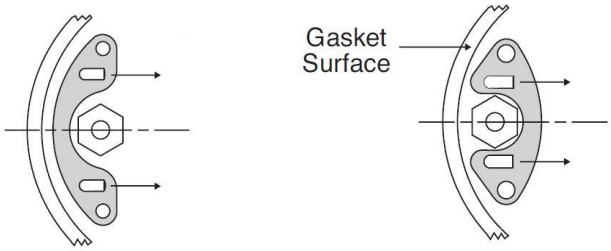


Fig. 1 shows CORRECT ALIGNMENT of guide pins. When correctly aligned, lever can be moved sideways the same distance to the right **(Fig. 2)** as to the left **(Fig. 3).**

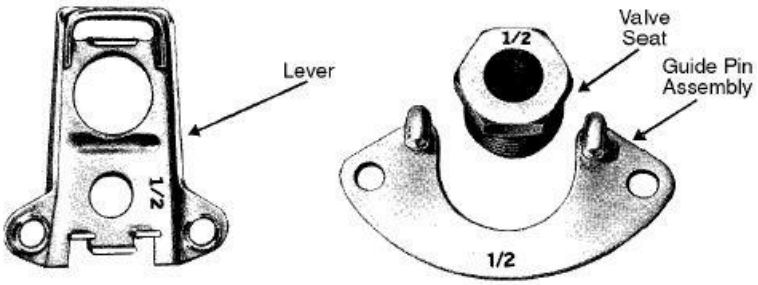
Figs. 4 & 5 show two examples of INCORRECT ALIGNMENT. Guide pins should be bent in direction of arrows until they center in holes as shown in Fig. 1.

Alignment of Guide Pins. To check the alignment of the guide pins, hold the lever assembly against the valve seat with the valve contacting its seat, and the two fulcrum points resting on the face of the seat. When the lever is held in this position, the guide pins should be central in the guide pin holes. See Fig. 1. There should be equal side-to-side movement of lever as shown in Fig. 2 and Fig. 3. It is a very simple matter to bend the pins until they are centrally located. Care should be taken so that the pins will remain perpendicular to the guide pin plate so that the lever can drop until it rests on the guide pin hooks.



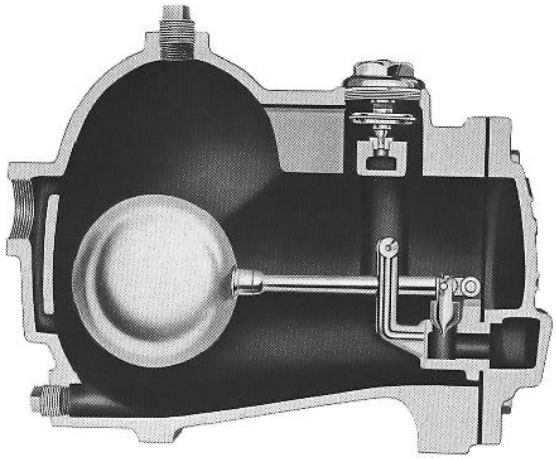
Guide Pin Assembly Installation. Install with guide pins pointing away from the adjoining gasket surfaces as shown above.

The Lever Assembly is hooked over the guide pins. In a few sizes of traps, particularly at low pressures, the valve lever assembly must be slipped on the guide pins before the guide pin assembly is fastened into position.



Diameter of orifice is stamped on valve parts.

BALL FLOAT TRAP



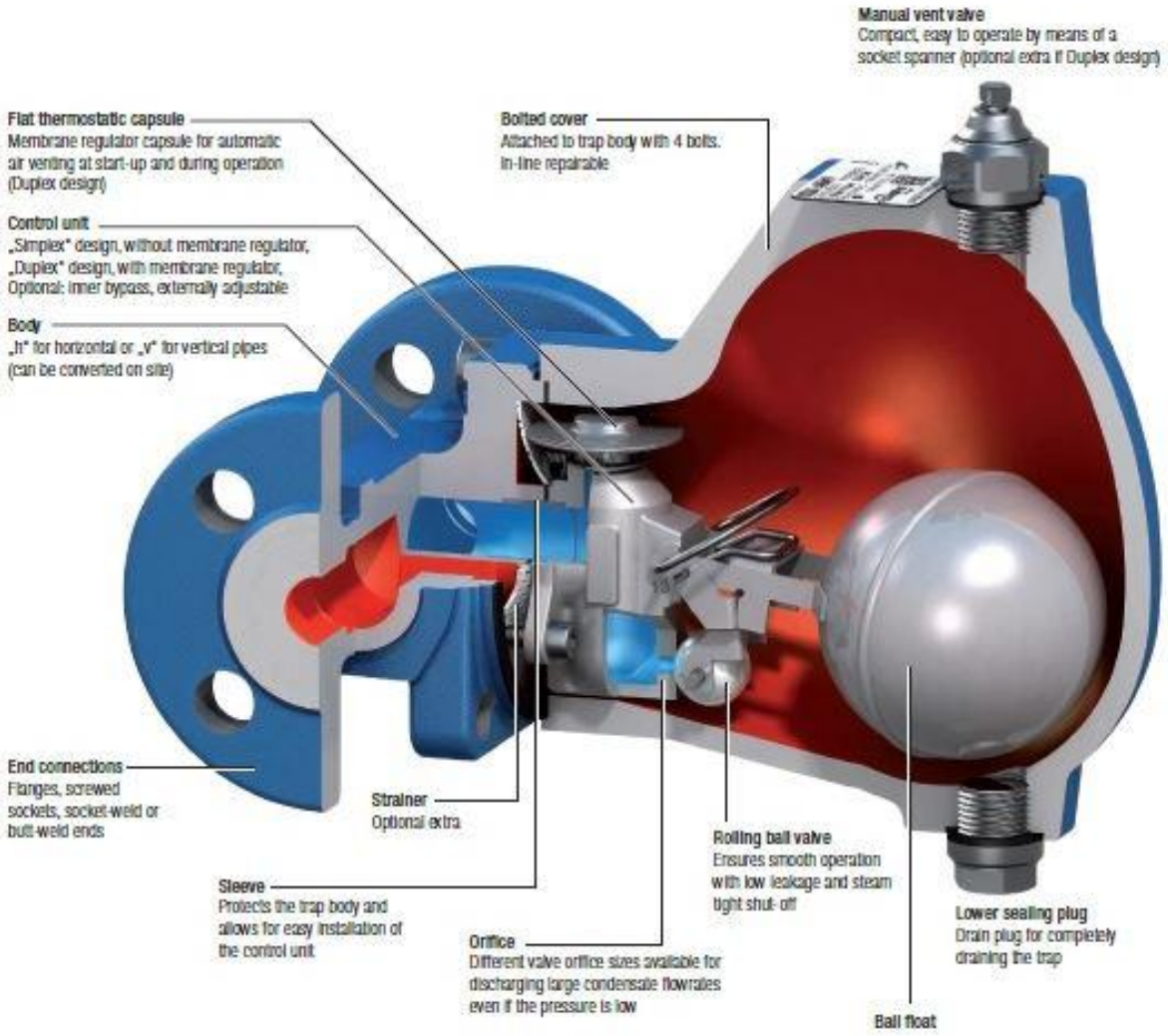
The ball float trap operates on the principle that a hollow enclosed steel ball will float on the surface of the water when surrounded by condensate and will sink when surrounded by steam. The ball is usually attached to a stem that is in turn attached to a needle and seat. Some traps have free-floating balls, the curvature of the ball fits into the curvature of the seat at the outlet. On the floats with a stem, as the condensate in the trap rises, the float also rises, opening the discharge port in the seat and allowing the condensate to leave. On the free-floating ball traps, the ball itself opens and closes the discharge port by its position inside the trap. Important notes about the ball float trap are:

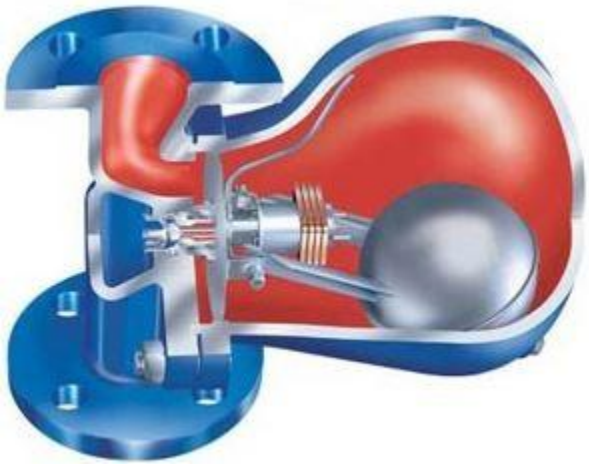
1. These type of steam traps are the most likely to become air-bound. Vents are usually provided in the top of the trap to remove the air. Float type traps that have thermostatic vents are referred to as F & T traps.

2. The discharge from a float trap is usually continuous. This can speed wear on the pin and seat.

3. Dirt and debris under the float can keep the float from closing the outlet valve.

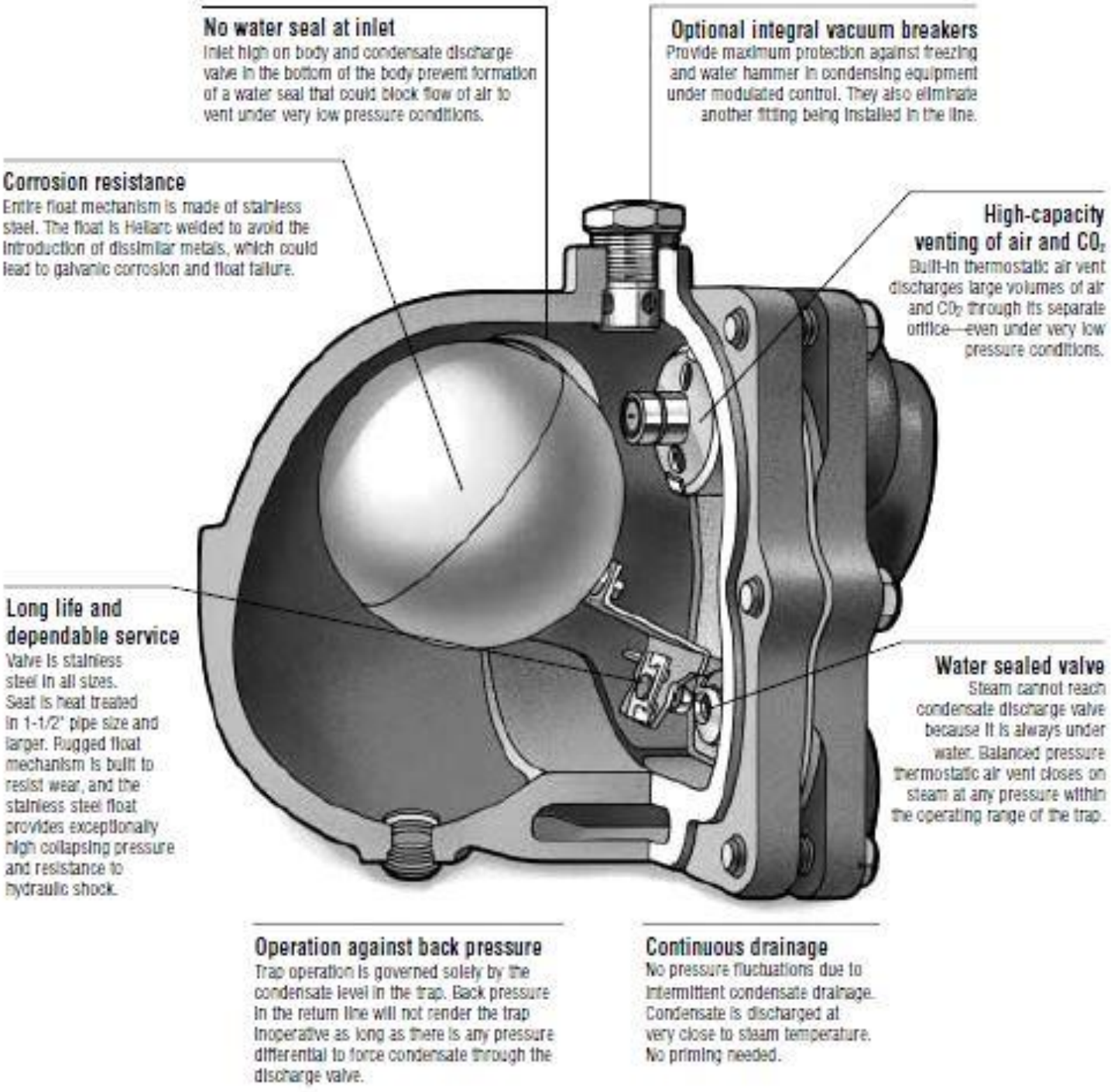
4. The ball can become crushed by water hammer.


Manual vent valve
Compact, easy to operate by means of a socket spanner (optional extra if Duplex design)
Flat thermostatic capsule
Membrane regulator capsule for automatic air venting at start-up and during operation (Duplex design)
Bolted cover
Attached to trap body with 4 bolts. In-line repairable
Control unit
„Simplex" design, without membrane regulator, „Duplex" design, with membrane regulator, Optional: inner bypass, externally adjustable
Body
„h" for horizontal or „v" for vertical pipes (can be converted on site)
End connections
Flanges, screwed sockets, socket-weld or butt-weld ends
Strainer
Optional extra
Sleeve
Protects the trap body and allows for easy installation of the control unit
Orifice
Different valve orifice sizes available for discharging large condensate flowrates even if the pressure is low
Rolling ball valve
Ensures smooth operation with low leakage and steam tight shut- off
Lower sealing plug
Drain plug for completely draining the trap
Ball float



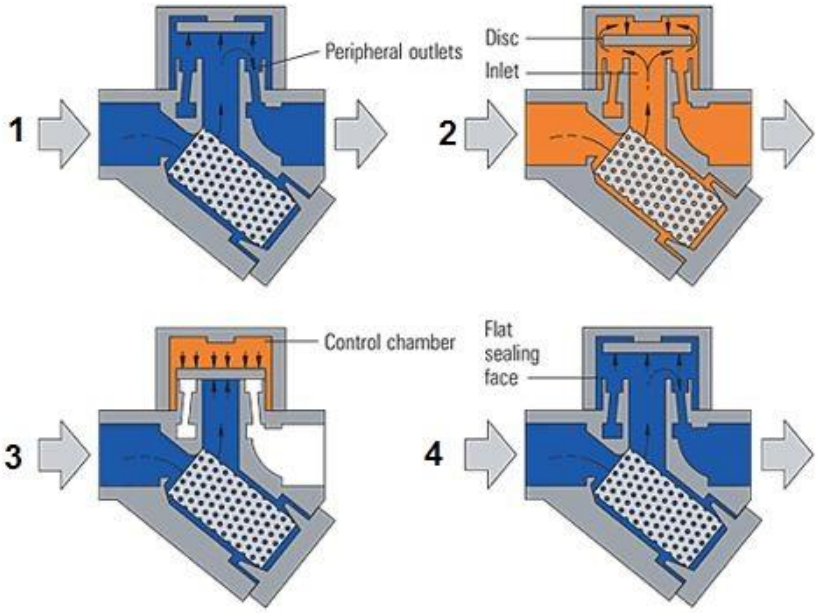
5. The float trap must be installed with the float valve closing the discharge port by gravity. This means different traps are used for vertical pipes than for horizontal pipes.

FLOAT and THERMOSTATIC TRAP


No water seal at inlet
Inlet high on body and condensate discharge valve in the bottom of the body prevent formation of a water seal that could block flow of air to vent under very low pressure conditions.
Optional integral vacuum breakers
Provide maximum protection against freezing and water hammer in condensing equipment under modulated control. They also eliminate another fitting being installed in the line.
Corrosion resistance
Entire float mechanism is made of stainless steel. The float is Heliarc welded to avoid the introduction of dissimilar metals, which could lead to galvanic corrosion and float failure.
High-capacity venting of air and CO_2
Built-in thermostatic air vent discharges large volumes of air and CO_2 through its separate orifice—even under very low pressure conditions.
Long life and dependable service
Valve is stainless steel in all sizes. Seat is heat treated in 1-1/2" pipe size and larger. Rugged float mechanism is built to resist wear, and the stainless steel float provides exceptionally high collapsing pressure and resistance to hydraulic shock.
Water sealed valve
Steam cannot reach condensate discharge valve because it is always under water. Balanced pressure thermostatic air vent closes on steam at any pressure within the operating range of the trap.
Operation against back pressure
Trap operation is governed solely by the condensate level in the trap. Back pressure in the return line will not render the trap inoperative as long as there is any pressure differential to force condensate through the discharge valve.
Continuous drainage
No pressure fluctuations due to intermittent condensate drainage. Condensate is discharged at very close to steam temperature. No priming needed.

IMPULSE or THERMODYNAMIC TRAP

The impulse trap operates on the principle that hot water under pressure will flash into steam when its pressure is reduced.



The thermodynamic trap is an extremely robust steam trap with a simple mode of operation. On start-up, incoming pressure raises the disc, and cool condensate plus air is immediately discharged from the inner ring, under the disc, and out through peripheral outlets, Figure 1.

The trap operates by means of the dynamic effect of flash steam as it passes through the trap, as depicted in Figure 2. The only moving part is the disc above the flat face inside the control chamber or cap.

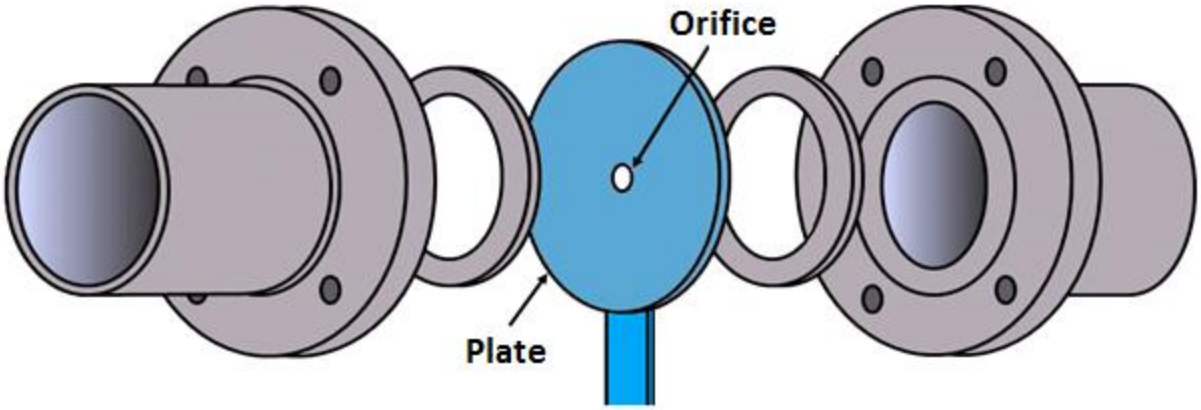
Hot condensate flowing through the inlet passage into the chamber under the disc drops in pressure and releases flash steam moving at high velocity. This high velocity creates a low pressure area under the disc, drawing it towards its seat, Figure 3.

At the same time, the flash steam pressure builds up inside the chamber above the disc, forcing it down against the incoming condensate until it seats on the inner and outer rings. At this point, the flash steam is trapped in the upper chamber, and the pressure above the disc equals the pressure being applied to the underside of the disc from the inner ring. However, the top of the disc is subject to a greater force than the underside, as it has a greater surface area.

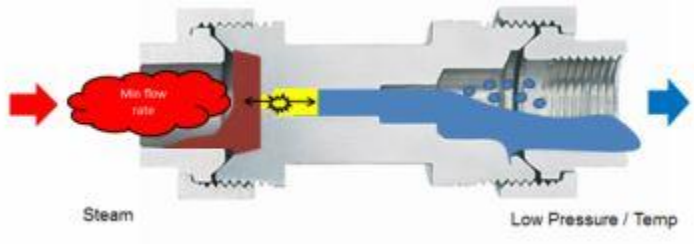
Eventually the trapped pressure in the upper chamber falls as the flash steam condenses, Figure 4. The disc is raised by the now higher condensate pressure and the cycle repeats

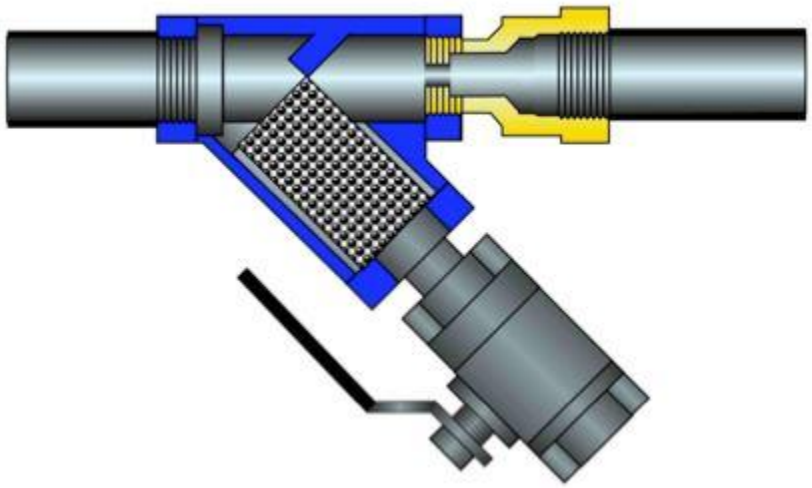
The rate of operation depends on steam temperature and ambient conditions. Most traps will stay closed for between 20 and 40 seconds. If the trap opens too frequently, perhaps due to a cold, wet, and windy location, the rate of opening can be slowed by simply fitting an insulating cover onto the top of the trap.

ORIFICE TRAP

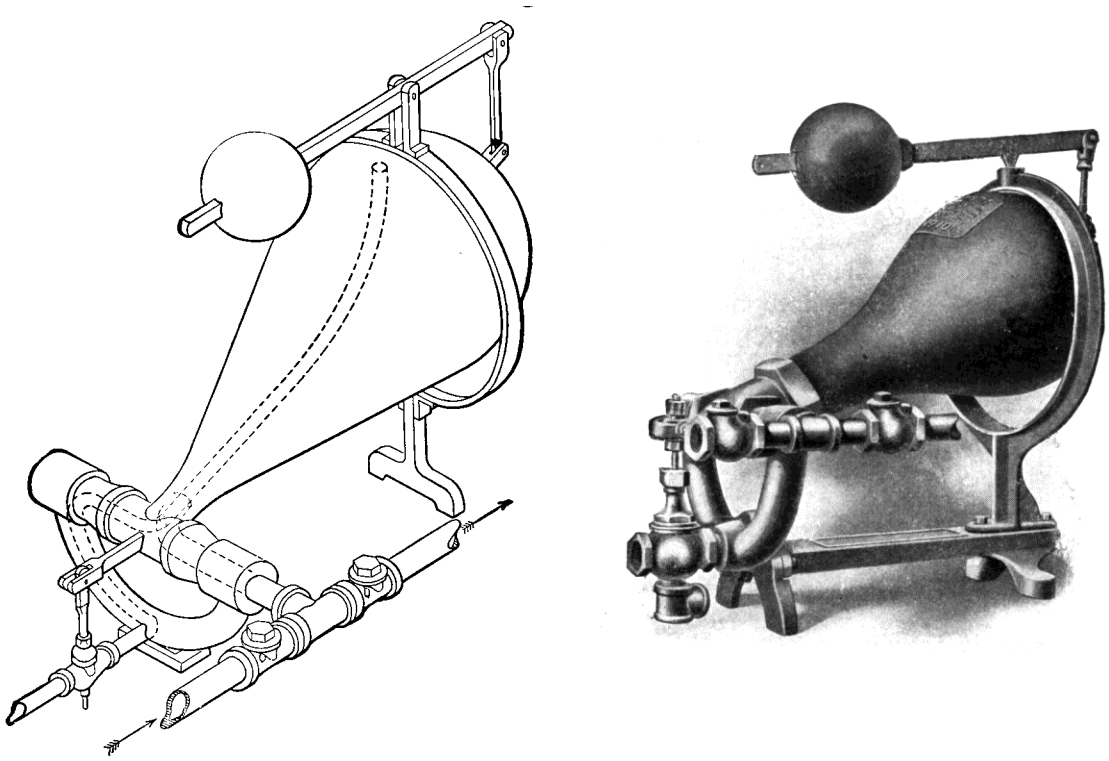


The orifice trap is simply a small hole that controls how much condensate can pass through. Obviously the condensate supply must be constant and the hole sized correctly or one of two conditions will occur. Either the condensate will back up in the pipe or steam will blow through. This limits their usefulness to low capacity applications. A strainer with a mesh smaller than the orifice must be placed in front of it or else it will clog with debris

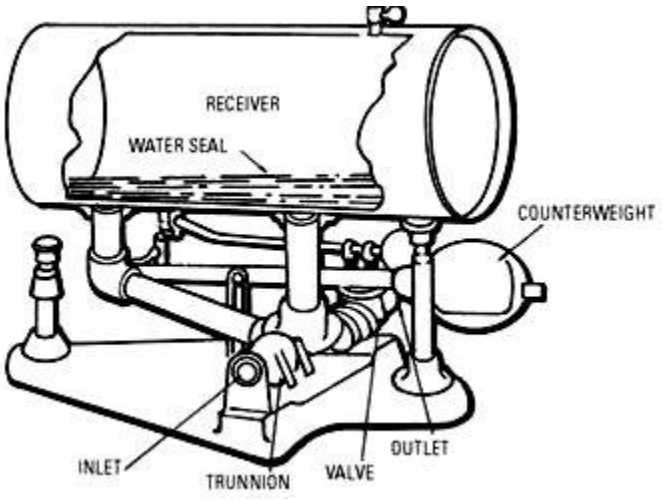




RETURN TRAPS



The Bundy return trap is used mainly to return condensate to a heating boiler located in the basement with the radiators located above the boiler and draining to the return trap by gravity. The Bundy trap has a large hollow cast iron or steel ball that pivots on a hollow yoke. A counterweight mounted to the ball and attached on a pivot to the circular frame that surrounds the ball holds the ball in the filling position until enough condensate has accumulated inside the ball. When enough condensate has filled the ball, the ball drops by gravity, and the movement of the ball opens a steam line from the boiler, equalizing the pressure in the ball to that of the boiler and the water drops by gravity into the boiler. Check valves prevent the condensate from backing up into the return line. Check valves also prevent the boiler water from backing up into the Bundy trap. The trap must be located at least three feet above the boiler so that enough static head is developed to freely drain the trap. Tilting traps perform the same basic function.



STEAM TRAP MAINTENANCE

You need to catalog all the steam traps in your facility, Put identifying metal tags on all of them, and start a spreadsheet of repair dates. If steam is coming out vents in the roof, you likely have trap problems. You were hired to keep costs low. Showing savings in fuel bills is one of the best ways to do it. Keeping your steam traps in good repair is one of the easiest ways to achieve that goal.

STEAM TRAP PROBLEMS

1. As a trap's pin and seat start to wear from repeated cycling, steam starts to leak past the seat. As the steam starts to flow past the seat it forms grooves in the seat, allowing more and more steam to leak past. The longer you wait to fix the trap, the more money you waste.

2. Dirt and metal shavings are carried along in the pipe until they wind up at the steam trap. This either clogs the filter and will not allow condensate to pass or a piece of debris will jam between the pin and seat and hold it open.

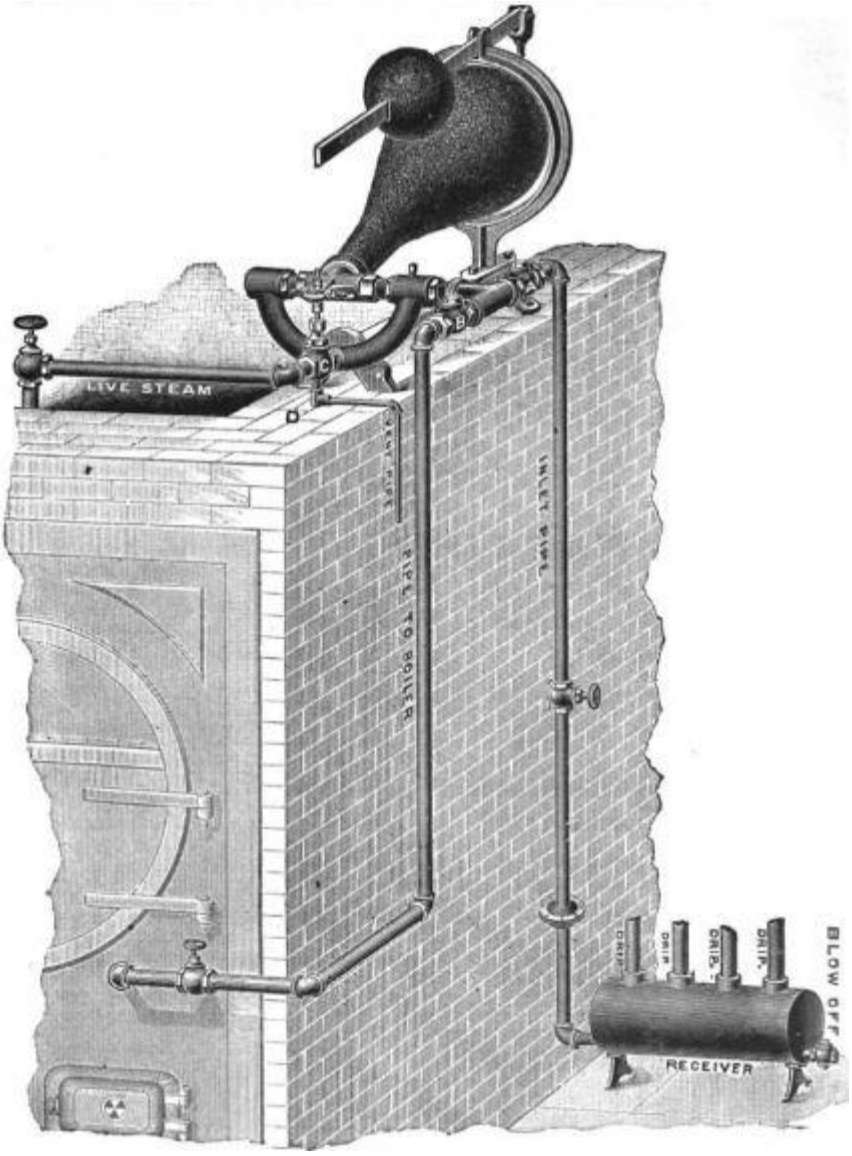
3. Vibration and water hammer in the piping can cause the valve linkage to come apart or else the linkage will wear out prematurely.

4. Any trap sitting outside is subject to freezing. Consult your trap representative for his prevention advice.

Beware the trap salesman who tries to get you to change all your old traps at one time. While it is true that replacing all the traps at one time will show a remarkable increase in fuel savings if proper maintenance has not been done in the past, it does not mean that his traps will last any longer than the old traps you just replaced. If you have a number of traps the same size, you would be better off to get 3 traps each from the different vendors and replace some of your old traps. Then you can make a better decision about which vendor's traps are lasting the longest. Call other powerhouses. They will be glad to give recommendations.

Chapter 13 Questions

1. On what principle does the thermostatic trap operate on?
2. On what principle does the bucket trap operate?
3. On what principle does the inverted bucket trap operate on?
4. On what principle does the ball float trap operate on?
5. On what principle does the impulse trap operate on?
6. On what principle does the orifice trap operate?
7. Which traps need to be primed before they will operate?
8. Which trap is most likely to become air bound?
9. Which traps are most susceptible to water hammer?



Chapter 14

FUELS

The Boiler Operator must be familiar with the many types of fuels that can be burned in boilers and their individual traits that determine how to burn that fuel with minimum smoke and maximum economy. The fuels that we will be studying are:

1. coal and lignite
2. oil
3. gas
4. waste fuels
    a. bagasse
    b. sawmill tailings
    c. municipal waste

COAL

Coal is a solid fuel found in layers at various depths in the earth. These deposits of coal are scattered throughout the United States but the greatest commercial deposits are in the Appalachian Mountain region in the east and the Montana, North Dakota, and Wyoming regions to the west.

Coal is classified by rank depending upon chemical analysis. Due to the varying nature of coal, these rankings are rather arbitrary and there are no distinct lines to define the differences between different ranks of coal.

TYPES OF COAL

1. Anthracite coal has a deep black color, and a shiny semi-metallic luster. It has the highest carbon content and is the hardest of all the coals. It ignites slowly and burns at a high temperature with little smoke and a short clear bluish flame. It burns freely without softening or swelling. Nearly all Anthracite coal comes from three small fields in Eastern Pennsylvania.

2. Semi-anthracite starts burning more readily and rapidly than anthracite. It can split upon burning and the smaller sizes can fall through the grate. It swells during burning but it does not cake. Semi-anthracite has less density, hardness, and metallic luster than anthracite. Handling semi-anthracite will leave your hands dirty where anthracite will not. It is found mainly in Pennsylvania, Arkansas, Virginia, and Alaska.

3. Semi-bituminous is similar in appearance to semi-anthracite but it has a more granular structure, is softer and contains more volatile matter. It crumbles easily so that handling may reduce it do fine particles and dust. It has a high heating value, low moisture, ash, and sulfur content and burns freely without producing objectionable smoke. Most semi-bituminous coals will cake together as they burn, with a short clear flame. It is found in Pennsylvania, West Virginia, Arkansas and Oklahoma.

4. Bituminous, known as soft coal is found in most coal producing states and is used more extensively than any other fuel in the generation of steam. Bituminous coal burns with a long bright shining flame. The physical properties of the different grades vary within wide limits, and no classification so far made has met with general approval. Bituminous coals range in color from pitch black to dark brown, and in hardness from that of the lignites to that of semi-bituminous. The volatile matter and fixed carbon content are about equal, but this is also true of sub-bituminous coal and lignite. One distinguishing feature which serves to separate bituminous from the lower rank coals is that of weathering. Bituminous coals are only slightly affected chemically by weathering, unless exposed for years; and then, although the coals consists of small particles, each particle is a prismatic fragment, whereas coals of a lower rank break into thin plates parallel with the bedding. Bituminous coals are either caking or non-caking. The caking bituminous tends to form into a solid mass when heated in a retort or furnace, while the non-caking bituminous burns freely without fusing. Coals suitable for making commercial coke are called coking coals, but as certain grades of coke can be made from free-burning coals the term is somewhat of a misnomer. Practically all coking coals are of the caking variety, but the reverse is not necessarily true. The high-volatile coals of western Pennsylvania, eastern Ohio, eastern Kentucky, and parts of West Virginia, frequently grouped under the heading "Pittsburgh coal", or "Pittsburgh Mining District" possess caking qualities to a greater or lesser degree, but not to the extent of the semi-bituminous coals. The non-caking variety is generally known as free-burning and is found chiefly in the Western and Middle Western States. Coking coal is rich in volatile hydrocarbons and is valuable in gas manufacture, and constitutes a large percentage of the steam fuel used in the Eastern States. Michigan bituminous is free-burning, but has a considerable tendency to clinker. The coals found in Illinois, Indiana, and Missouri are practically all free-burning. Iowa coals are of much lower grade than those just mentioned, because of their large moisture and ash content. Kentucky, Tennessee, and Alabama bituminous coals are high-grade and free-burning, although the coals from some localities in this district have a tendency to clinker badly. The high-volatile bituminous coals of Colorado, Wyoming, Washington, and Oregon include both caking and non-caking varieties.

5. Sub-bituminous coal approach the lowest grades of bituminous in structure and heating value. When sub-bituminous is exposed to the weather it slacks rapidly, the lumps becoming brittle and crumbling into fine particles. This coal is sometimes termed "black lignite". Large deposits of sub-bituminous coal are found in the Western states, principally in Colorado, Wyoming, Montana, New Mexico, Oregon and Washington.

6. Lignite or brown coal has a brown woody structure, low heating value, and a high moisture content. Lignite burns with a long yellow flame similar to a wood fire. When freshly mined it can contain as much as 35% moisture, with exposure to air it loses moisture and starts to break into fine particles. Since it has these properties, it cannot be shipped long distances and is usually burned at a plant specifically built near the deposits to exploit the massive reserves that the United States possesses. Lignite is found in North and South Dakota, Texas, Montana and Alaska.

HEATING VALUES OF COAL

HEATING VALUES OF COAL				
TYPE OF COAL.	BTU /LB.	CARBON	HYDROGEN	SULFUR
Anthracite	13000 to 14500	92% to 98%	3%	.7%
Semi-Anthracite	13600 to 14800	86% to 92%	4%	1%
Semi-Bituminous	14000 to 15000	14000 to 15000	4%	2%
Bituminous	11000 to 14350	11000 to 14350	5% to 6%	1.5% to 3.5%
Subbituminous	8500 to 11000	8500 to 11000	6%	1%
Lignite	6900 to 8300	6900 to 8300	7%	1%

Due to the varying nature of coal in different fields and even within the same seam the values in the above chart can only be approximations. The constituents of coal are:

1. Nitrogen
2. Oxygen
3. Carbon
4. Ash
5. Sulfur
6. Hydrogen
7. Water

The easy way to remember this to take the first letter of each constituent. For example Nitrogen = N, Oxygen = O, etc. Then remember that you have NO CASH but you have water. Determining the amount of each element in the coal is called the Ultimate Analysis. The elements in the coal that actually burn and provide heat are Carbon, Hydrogen, and Sulfur. The Sulfur is considered to be a bad constituent of the coal due to the Sulfur-Dioxide that is produced when sulfur burns. The Sulfur-Dioxide combines with water in the atmosphere to form Sulfurous Acid which causes acid rain. The sulfur in coal also deteriorates the metal stacks and breeching from the boiler. Due to regulations from the Environmental Protection Agency, special equipment must be added through which the exhaust gasses must pass before going out the chimney if high Sulfur coal is burned. Examples of these are limestone scrubbers and electrostatic precipitators. The limestone scrubbers are wet sprays of an alkaline limestone that neutralize the acidic Sulfur-Dioxide. The electrostatic precipitator gives the flue gas a static electrical charge and then causes the ash and sulfur to cling to plates where they are periodically cleaned.

PROXIMATE ANALYSIS

The proximate analysis of coal finds the amount of moisture, volatile matter, fixed carbon and ash in the coal. In order to find the proximate analysis of coal, the following method is used.

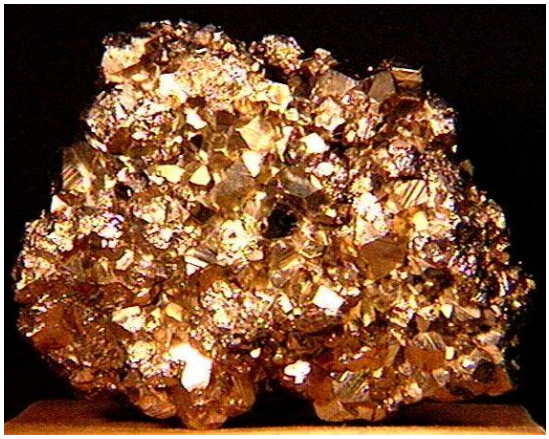
1. A one gram pulverized typical sample of the coal is placed into an oven at 220 degrees Fahrenheit. After one hour the sample is removed and weighed. The difference between the weight now and the one gram at the start is the amount of moisture in the sample.

2. The sample is next placed in a platinum crucible with a tight lid. For 7 minutes the sample is heated to 1700 degrees Fahrenheit. The sample is again weighed at the end of 7 minutes. The weight difference between before and after is the amount of volatile matter in the coal.

3. The cover is then taken off the platinum crucible and is placed back into the 1700 degree oven to burn the rest of the coal to ash. The difference between the weight of the sample before it is completely burned and the ash is the amount of fixed carbon in the coal. The ash is the weight of the residue left after final burning. If the coal has 10% ash and the boiler uses ten tons of coal per day, then 2000 lbs. of ash must be removed.

Ash is mainly silicon dioxide and aluminum oxide with smaller amounts of ferric oxide, calcium oxide, magnesium oxide, and alkali oxides. Ash is bought for the same price as coal and you also pay to transport the ash in the coal to the boiler room. After the coal is burned you must pay for equipment to remove the ash, the labor involved, and the transportation and landfill costs to remove the ash.

Pyrites and tramp iron that come with coal are compounds of sulfur and iron.



Tramp Iron from Pulverizer

Coal must be broken into different sizes so that it will burn evenly on the grate or stoker. The type of burning apparatus will determine how finely the coal must be broken. The names of the sizes that have been passed down through the years reflect the attempt to relate the size of the coal to ordinary objects.

The following table will show the sizes that would pass through a certain sized square wire mesh but would not pass through the smaller mesh. There are different size classifications for anthracite and bituminous coal.

COAL SIZING AND NAMES FOR ANTHRACITE COAL IN INCHES		
	PASS THROUGH	WILL NOT PASS THROUGH
Broken	4 1/2	3 1/4
Egg	3 1/4	2 5/16
Stove	2 5/16	1 5/8
Chestnut	1 5/8	7/8
Pea	7/8	9/16
No.1 Buckwheat	9/16	5/16
No.2 Buckwheat or Rice	5/16	3/16
#3 Buckwheat	3/16	3/32
Culm	3/32	
courtesy Babcock & Wilcox		

COAL SIZING FOR BITUMINOUS COAL IN INCHES		
	WILL PASS THROUGH	WILL NOT PASS THROUGH
Lump	Anything larger than 5	5
5 X 2 Egg	5	2
Nut	2	1 1/4
Stoker	1 1/4	3/4
Slack	3/4	

COAL SHIPMENT METHODS

Coal is usually shipped from the underground coal mines of the East or strip mines of the West by railroad. Special unit trains are built that allow the coal cars to be rotated and dumped without unhooking the car from the rest of the train. Smaller shipments use a bottom unloader. The car is set over a grate and the bottom of the rail car is opened and the coal is dropped onto a conveyor at the bottom of the hopper. In Northern climates the coal can freeze and refuse to drop. Shakers are usually provided to vibrate the rail car to get the coal to drop. If it still will not fall the Boiler Operator or Coal Handler must use portable heaters to try to free the coal. Some plants have warming sheds where the cars are sent to thaw. Coal can be pre-treated at the mine to try and prevent freezing, but the cost is usually too high for smaller plants to afford.

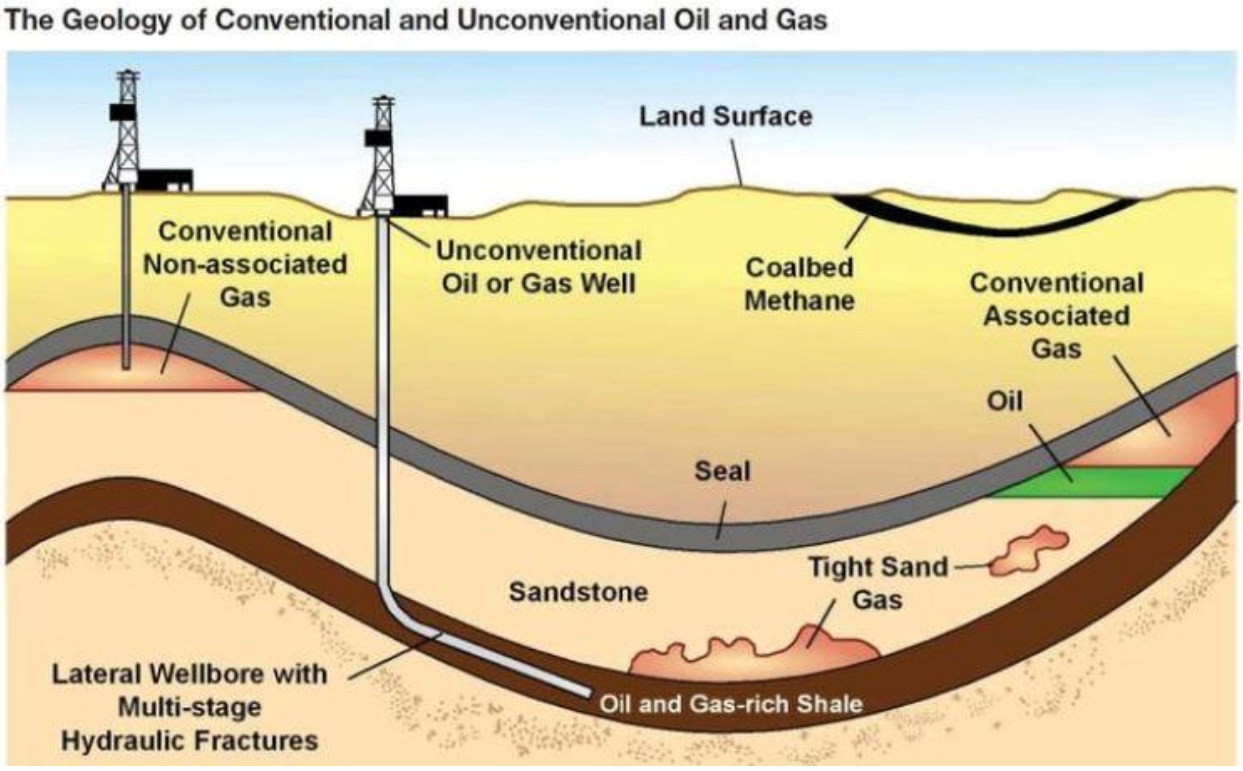
In the Appalachian mountains coal is shipped by truck from mines that are too far from the railroad to be serviced by train.

The Detroit Edison Utility Company (DTE) owns low sulfur coal mines in Montana. The coal is sent by rail to Superior Wisconsin where the coal is loaded on huge Great Lakes freighters. The Coal is then shipped around Lake Superior and Lake Huron to powerplants along the Michigan coastline. The coal is unloaded by conveyors on board the ships to the coal storage areas outside the plant.

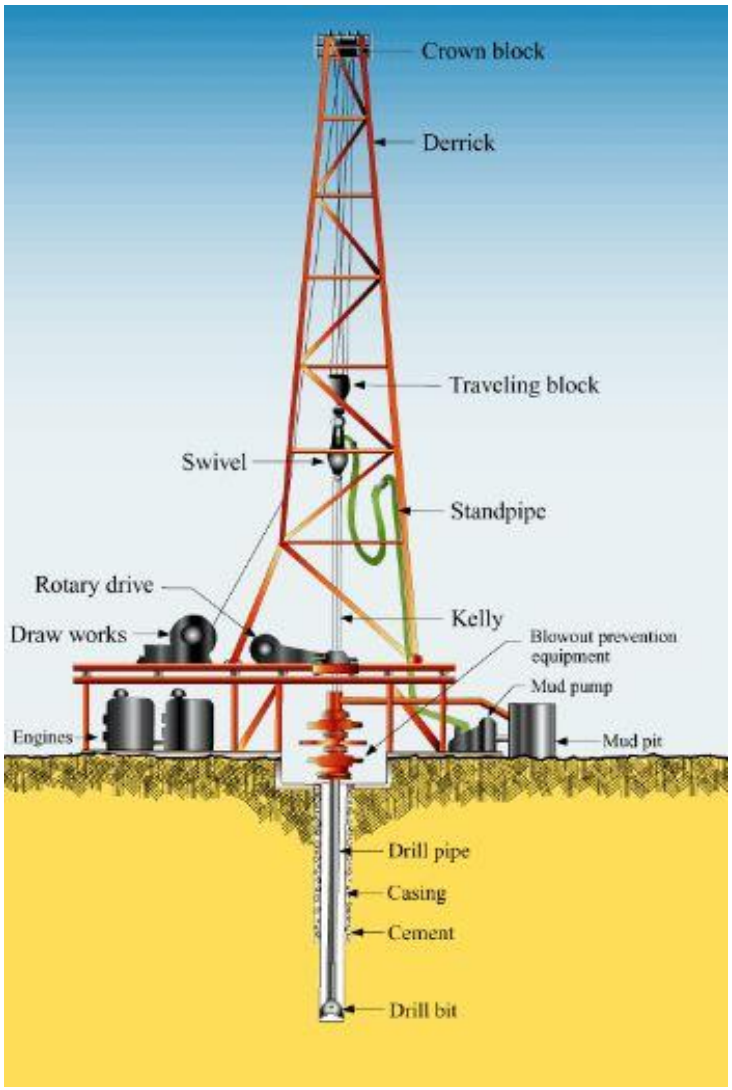
Self-Unloader on Great Lakes Freighter

FUEL OIL

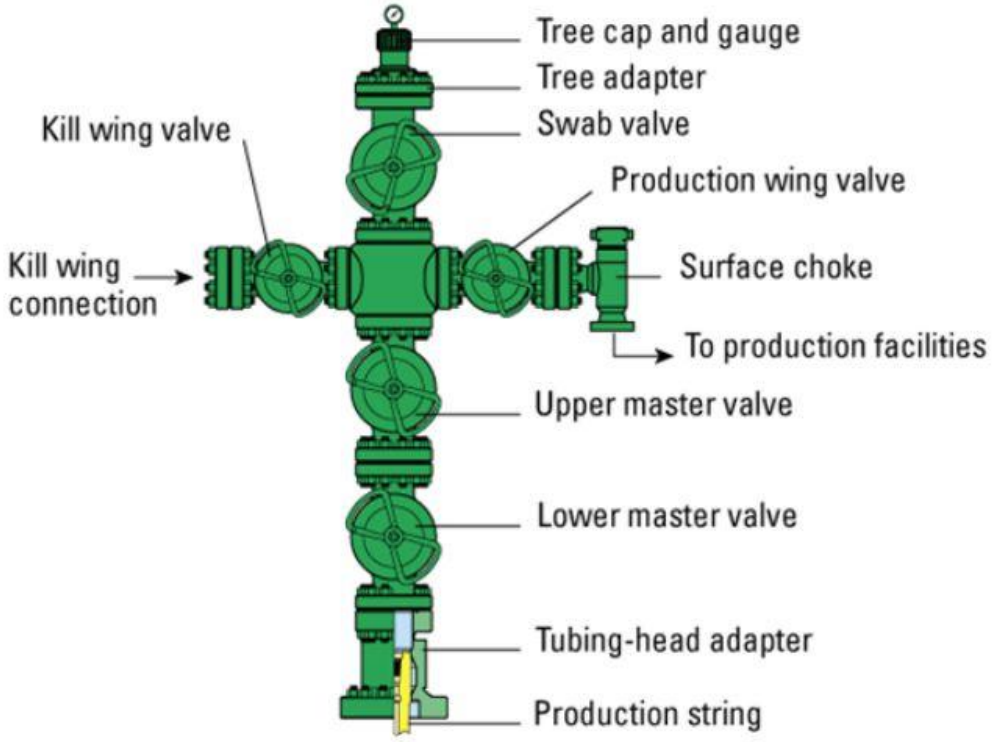
Oil is found by drilling into the oil fields located at different depths in the earth throughout the world. The oil deposits are often found around "Salt Domes" or along the fault lines created as the earth shifted from earthquakes and other geologic movements. Natural Gas deposits are often on the top of the oil deposits.



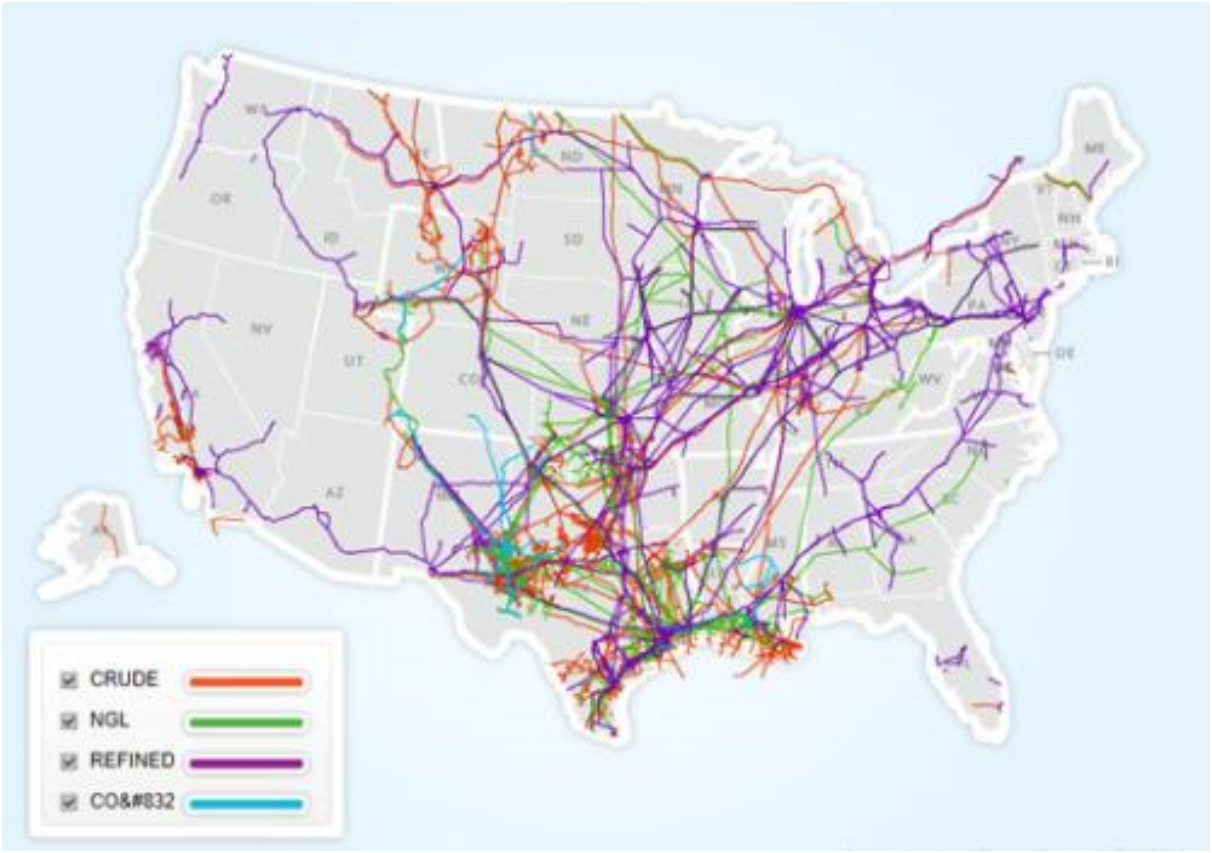
Geologists use seismic techniques of charting sound waves produced by small explosions or truck-mounted vibrating equipment to chart the geographical features deep in the earth. The sound waves can be processed by a computer to produce a vertical section of the layers of rock under the ground. By looking for salt domes and sedimentary basins, Geologists try to pinpoint the best location to drill for oil.



Before drilling, a derrick tall enough to handle three sections of 30 ft. pipe at a time is set up to allow the drill pipe to be screwed together above the ground. Drilling is done by screwing the 30 foot lengths of pipe together connected to a three-cone drill bit at the end that carves and chips its way down through the layers of rock. The drill bit and pipe go through a "Blowout Preventer" at the bottom of the derrick before entering the earth. The blowout preventer is a safety device consisting of valves and seals to allow the well to be valved off if the underground pressure causes a "gusher" that must be contained. The part of the well that is closest to the surface is lined with a large diameter steel casing to keep the oil and salt water from mixing with the ground water. Large pumps on the surface pump clay mud through the center of the drill pipe. As the mud reaches the drill bit it is forced out openings in the drill bit and heads back up the outside of the pipe back to the surface. This cools the bit and carries the cuttings back to the surface so the drill bit has a fresh bite on the rock it is drilling through. The mud also serves to fill the porous areas of the drill hole and keep fresh water from entering the drill hole. After drilling down 2000 to 3000 feet, the original drill bit is removed and a larger bit is used to ream the hole to a larger size. Then that bit is removed and larger diameter pipe called "surface casing" is set in place and cemented in around the outside of the pipe so that if oil is discovered, it will be contained within the steel casing. Then drilling continues. The mud is continually tested for the presence of oil and when it is discovered explosive "shaped charges" are sent down the well to shoot through the casing and open passages for the oil to flow into the well casing.



The oil flows up by natural pressure or by using downhole pumps through a "Christmas Tree" of valves that control the flow of oil or gas. The crude oil is "stabilized" by removing water and natural gas in settling tanks and then pipelines carry the crude oil to the refinery.



Marathon Refinery in Detroit

The refinery distills the different grades of fuel oil for use in powerplants. Fuel oil is Graded into six different categories and given the numbers 1 through 6. Number 3 is not usually included in any analysis because of the lack of a commercial use for that grade. Number 6 oil is sometimes referred to as "Bunker C". Some of the characteristics of these different fuel oils are in the table below. Given that oil is a natural product that comes from all over the world, these figures can only be approximations.

	BTU per LB.	BTU per Gal.	Flashpoint	Preheat temp
Number 1 oil	19800	136,000	100	Not needed
Number 2 oil	19500	138,500	100	Not Needed
Number 4 oil	19200	145,000	130	150
Number 5 oil	18800	146,000	130	175
Number 6 oil	18600	148,000	150	180-220

Notice that Number 1 fuel oil has a higher BTU value per lb. than Number 6 but less BTU's per gallon. As the API at 60 degrees Fahrenheit increases, the BTU's per lb. decreases.

Ignition Temperatures of fuel oil vary from 500 degrees F. for light fuel oils to 760 degrees for heavy fuel oils. Spark igniters can generate temperatures in excess of 3000 degrees F. and are used extensively to ignite fuel oil burners. Liquid oil does not burn. It is the gasses given off from the liquid oil that does the burning and some sort of atomization or dividing of the oil into small drops must be done to make the oil give off its gas readily so that complete combustion can occur in the furnace.

Fuel oil has many characteristics. Some of them are listed below:

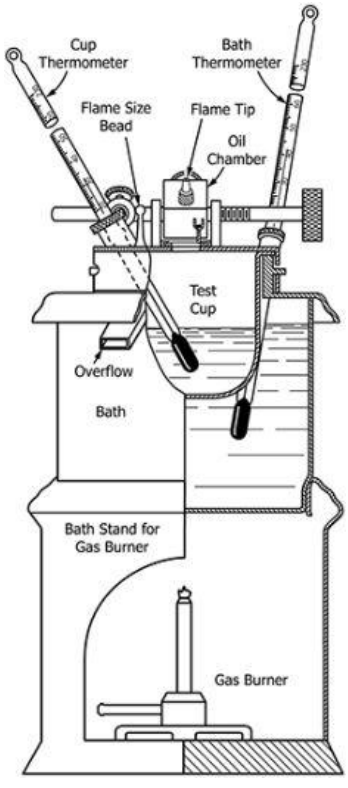
1. Viscosity: Viscosity is the oil's internal resistance to flow. The higher the viscosity, the thicker the oil. The colder the oil the slower the oil will flow. Number 6 fuel oil is so thick that it has a consistency similar to tar at room temperature. Number 4 and number 5 fuel oil need pre-heating in moderate or cold climates because they are too thick to flow through the pumps and piping without heating and the heat thins the oil. Number 6 needs preheating at all times. They also need to be heated to improve the complete combustion of the fuel at the burner. Viscosity is measured with a viscometer, timing how long a measured sample of the oil takes to drop through an orifice.

2. Flash Point: The point at which a fuel will give off a momentary flash of flame when heated and exposed to an ignition source, but will not continue to burn. If a fuel oil is heated above its flash point and a leak in the piping occurred, the oil could cause an explosion. For this reason, oil that needs to be pre-heated should be heated from 10 degrees to 50 degrees below its flash point until just before the burner.

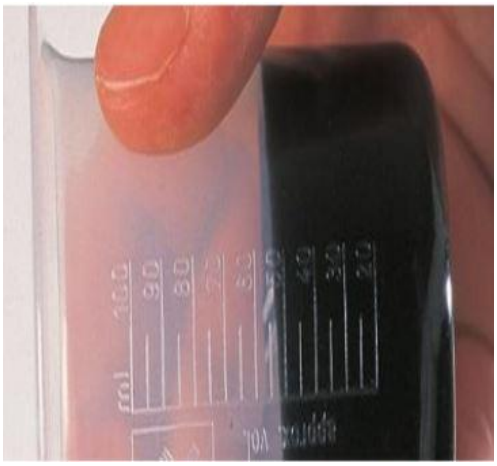
3. Pour Point: The temperature at which an oil will no longer flow when it is cooled in a cup and the cup is turned 45 degrees to empty the contents.

4. Specific Gravity: the weight of a fuel oil as compared to water. The specific gravity of oil is less than water so any water should be found on the bottom of the tank. The specific gravity of #6 fuel oil is very close to water and some water may be found on the surface of the oil.

5. Specific Heat: The amount of heat need to raise one pound of oil one degree Fahrenheit as compared to water. The specific heat of oil is usually taken as .5 or one-half that of water.

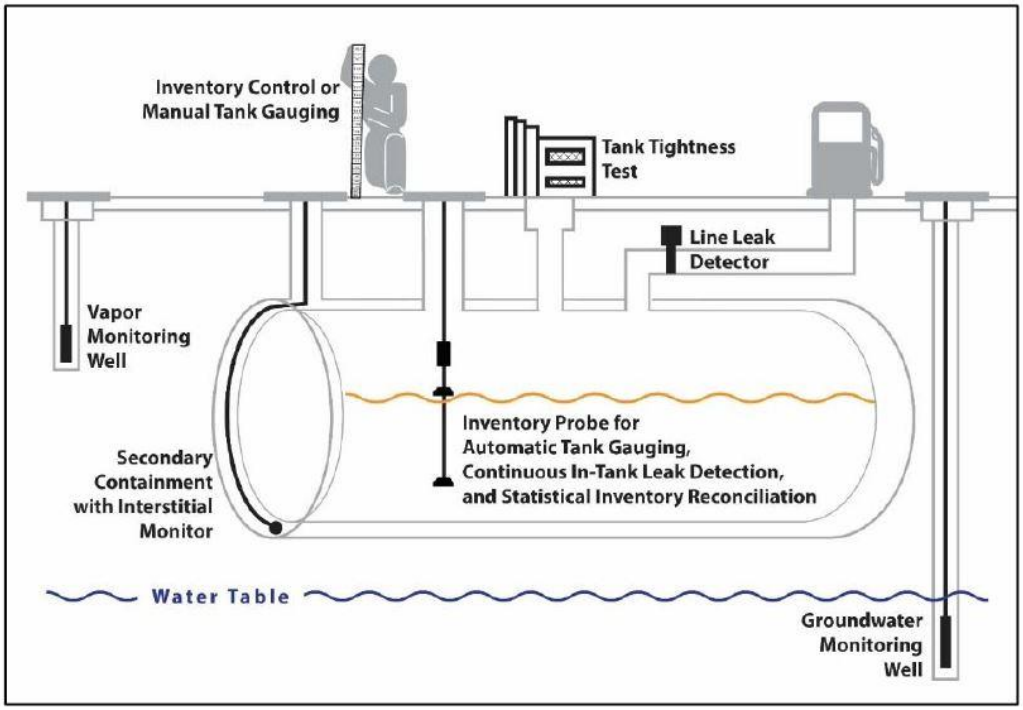


Flashpoint Tester



Pour Point Test

FUEL OIL TANKS



Fuel oil is usually stored in underground tanks at least two feet below the ground for the following reasons:

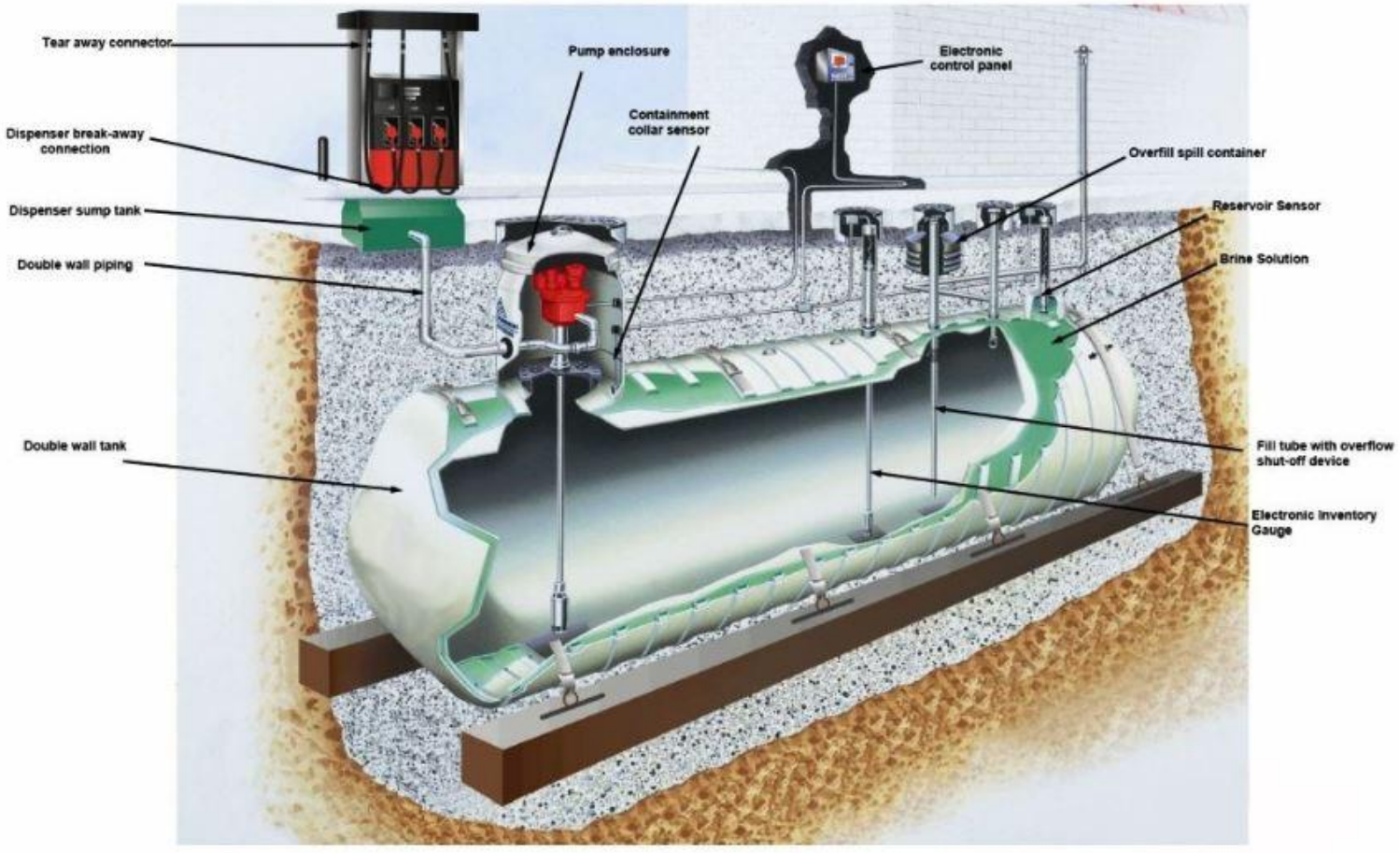
1. Less chance of an accident (someone puncturing the tank)

2. In case of a oil suction line breakage, the fact that the oil level is below the burner level will stop the oil from continuing to spill.

3. Occupies no space in the boiler room.

4. An above ground tank could only be 275 gallons or less and meet the National Board of Fire Underwriters rules. Most underground tanks are 10,000 gallons or more.

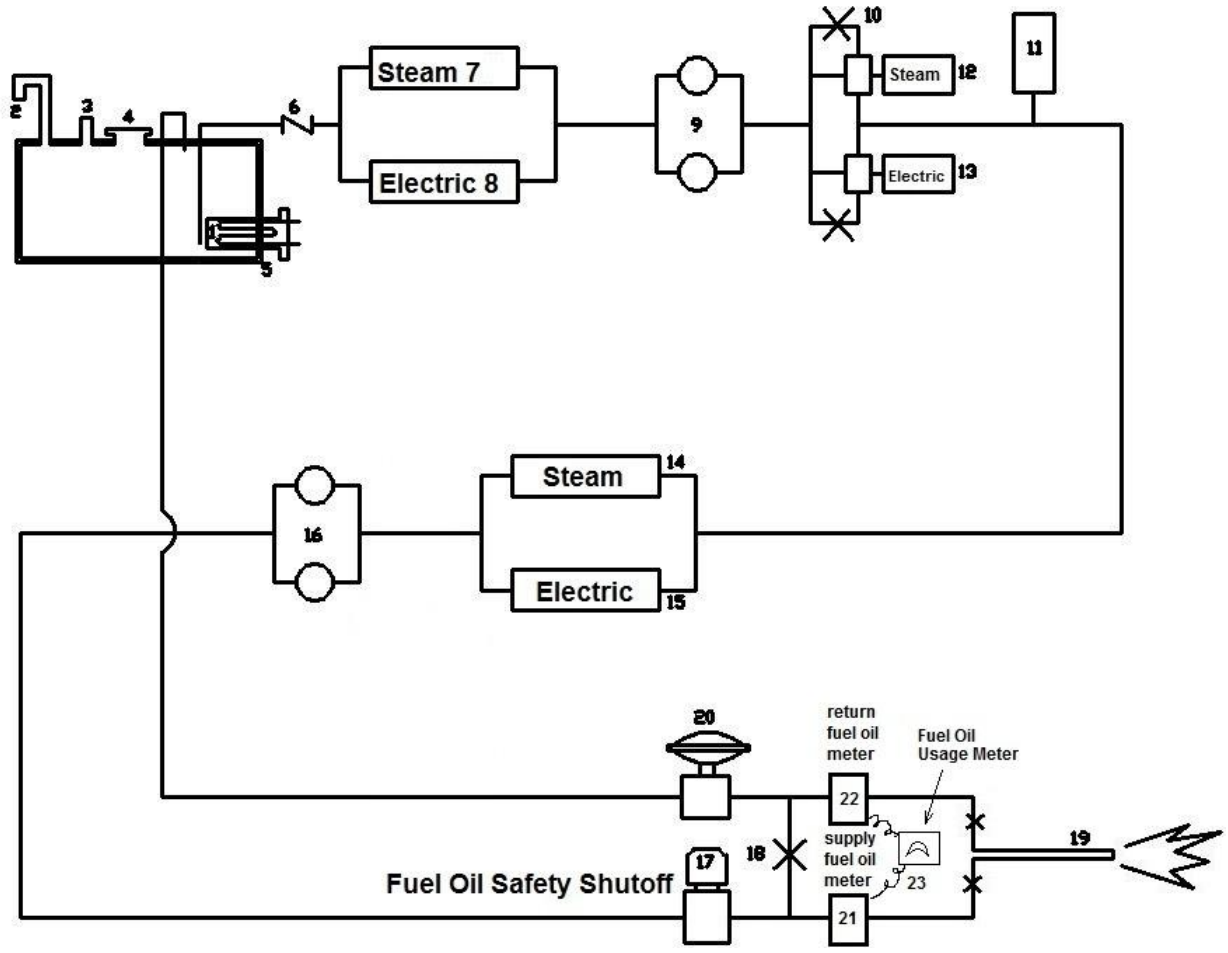
The disadvantage of steel fuel oil tanks is that they eventually leak and the fuel oil contaminates the groundwater. The Environmental Protection Agency has passed laws that all underground fuel storage tanks must have some form of leak detection by 1993. New steel fuel oil tanks should be double walled and all steel tanks should have some type of cathodic protection. Cathodic protection is a way to use DC electricity to prevent the ions in the steel from traveling into the surrounding soil which is a fancy way of saying that it helps prevent corrosion. Fiberglass tanks do not need cathodic protection because they do not rust. Buried oil piping should be made of copper tubing because it does not rust, it does not flake off on the inside, needs less joints, and it can flex without breaking as the tank settles. Monitoring wells, which are pits dug down to the water table at either end of the tank are needed to check if there has been an oil leak from the tank.



TYPICAL UNDERGROUND TANK PROTECTION SYSTEMS

Modern Fuel Oil Tanks must have interstitial monitors like the Veeder-Root TLS 350 to comply with EPA regulations.

FUEL OIL PIPING

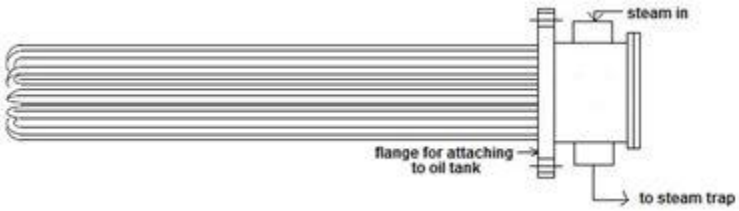


In order for a heavy fuel oil like # 4, 5, or 6 to get from the underground storage tank to the burners, the oil piping contains specific equipment to handle the fuel oil and guard against problems at the burners. Referring to illustration above, we will start at the storage tank. The suction line to the burners starts near the bottom of the tank at the tank suction heater. The line goes up through a check valve 6 and into the steam and electric heaters 7 and 8. After leaving the heaters they go the suction of the duplex strainer 9. From the suction duplex strainer, the suction line tees off to the inlet of both the electrical fuel oil pump and the steam driven duplex fuel oil pump 12 and 13, and past thermometer 11. From the discharge of the fuel oil pumps the line goes through a smaller set of steam or electric fuel oil heaters closer to the burner, number 14 and 15. After going through another set of duplex strainers with a finer mesh screen 16, the oil passes through the fuel oil safety shut-off 17 and through fuel oil supply meter 21 before going on to the burner. The excess fuel oil from the burner goes through a return fuel oil meter 22 and the actual fuel usage is calculated by the fuel oil usage meter 23. Fuel oil regulator 20 determines the firing rate. Fuel not used is returned to the storage tank. Before the burner is lit, the valves to the burner are shut off and the bypass valve 18 is opened to warm up the lines.

You may be required to draw a simple fuel oil system for your exam. This drawing contains all the essential parts.

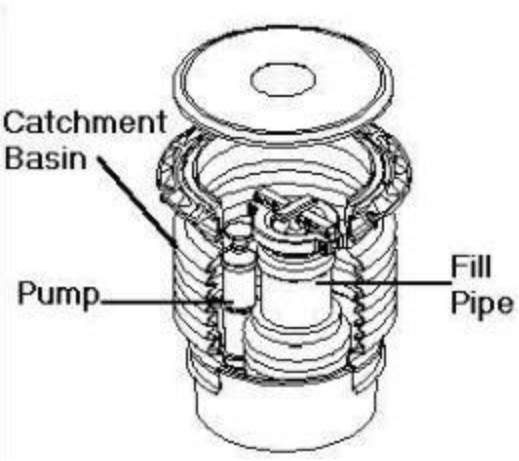
Now let's go back to the illustration and discuss each piece of equipment in greater detail. The storage tank is buried at least two feet underground. There is a steel or brick container built around the manhole from the top of the tank to ground level to gain access to the manhole.

Electric Heater



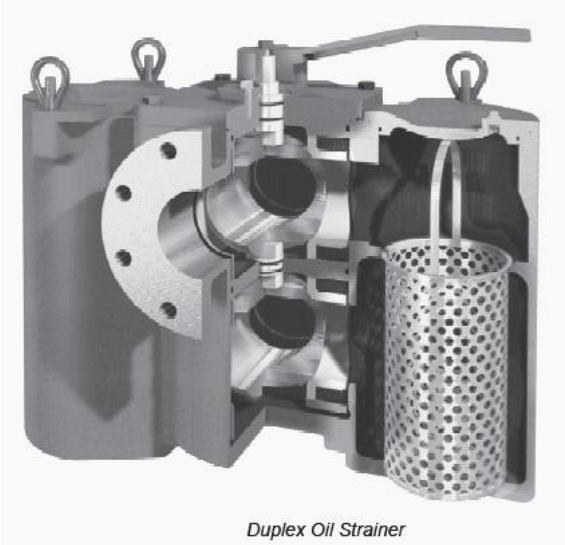
There is an electric and a steam heater in most underground storage tanks with heavy fuel oil. The electric heaters must be used until the boilers are started and steam is available. The steam heater at the bottom of the tank has a steam line feeding a coil in the heater to preheat the oil so that the oil will flow to the pump. Steam pressure at the heater should not be higher than 10 psi. The discharge from the steam line goes through a steam trap and usually to waste due to the danger of allowing oil leaks get back to the boiler. The tank has a measuring well to allow you to use a measuring stick to see how much oil is in the tank and whether there is any water at the bottom of the tank. A strike plate is installed at the bottom of a fiberglass tank so you don't punch a hole through the bottom of the tank with the measuring stick. A steam smothering line can be used to combat fire at the tank. The connection for the portable sludge pump is to allow a pump to be lowered to the bottom of the tank to rid the tank of sludge that comes with the heavy grades of oil on the fuel oil truck.

The truck gets the residue from the refinery and drops it into your tank. You not only pay for useless sludge that clogs the strainers, you pay to rid the tank of the sludge. Every tank must have a vent to allow the fuel oil to drop by gravity into the tank. The vent must have a cover over it to prevent rain from entering the tank and filling the bottom with water. If the tank is overfilled, the oil will come spewing out the vent. The fill line allows the oil delivery driver to drop the order into the tank. The oil fill can either be directly over the tank as shown or else it can be at a remote fill some distance from the tank. In either case the oil fill must have a spill container around the fill pipe to contain any spills that the driver causes. You must order the exact amount of oil so that the tank is not over 90% full. The oil has been heated so that it will flow from the truck. You pay by the gallon and heated oil takes up more volume. If the truck will not have a meter and the driver drops whatever the supplier filled the truck with. If it is more than the tank can hold, it will overflow and you will have to call the Governmental authorities. Some trucks have delivered #2 fuel oil to a #6 fuel oil tank by mistake and you would have to have the tank pumped out if this occurs because it will be unusable and dangerous in the furnace of your heavy oil installation. Stay with the truck until the oil has been delivered. The truck driver may take a nap while the oil is flowing and would not shut off the valve if an accident occurs.

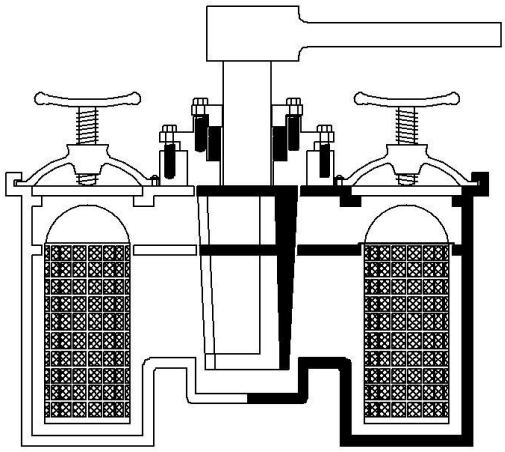


The approved oil spill container is illustrated above. The driver removes the cover and the special cap that fits over the end of the fill pipe. The hose has a mating connection that fits onto the end of the fill pipe to lock it in place while oil is being dropped into the tank by gravity.

The check valve 6 prevents air pockets from forming in the suction line during startup. There is a foot valve on the end of the suction line in the tank to keep the fuel oil line full from tank to pump suction.



Duplex Oil Strainer



The duplex fuel oil strainer allows one strainer basket to be cleaned while the other is in service. The handle is pulled over the clean strainer to put it into service and the other strainer that was being used is now ready to be cleaned. The screw handle on the top of the strainer is loosened and the cap removed. The basket is removed and dipped into a bucket of kerosene and brushed with a stiff bristle brush. After the strainer is cleaned it is replaced, the is cap put over it and tightened, and the strainer is now ready to be put back into service when the handle is turned again, usually after eight hours. The first strainer in line is the coarse strainer seen on the left. The fine mesh strainer is on the right.

As the suction strainer gets clogged, the gauge on the line between the strainer and the suction side of the pump will start showing a deeper vacuum.

As the discharge strainer gets clogged, the gauge on the line between the strainer and the discharge side of the pump will start showing an increase in pressure.

The duplex fuel oil suction strainer uses a coarse screen, from 16 to 20 mesh. The strainer for suction or discharge will either be wire mesh, metallic disk, or a perforated metal cylinder. Filter cloth is not used. This strainer protects the pump.

The duplex fuel oil discharge strainer uses a fine mesh screen, from 40 to 60 mesh. The coarse strainer protects the pump. The fine strainer is to prevent the burner tip from becoming clogged.

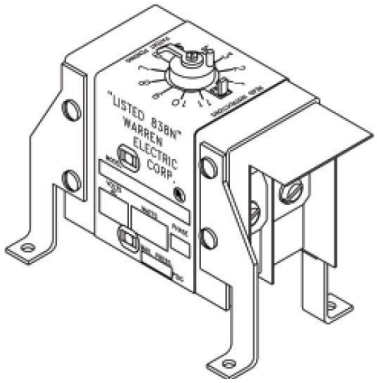
Both electric and steam driven pumps are used. The electric pump allows oil to be delivered to the burner before steam is generated by the boiler. The steam pump allows the boiler to run without electricity, if the other auxiliary equipment is also steam powered. Either one pump or the other will be run, not both at the same time unless a changeover is being made. Electric fuel oil pumps are of the gear type and are positive displacement as are duplex steam pumps. These pumps have a relief valve around the pump to prevent the pipe or casing of the pump from rupturing if the pump is started with the discharge closed.

The air chamber in the discharge line from the duplex pump will smooth the pulsations of the reciprocating motion of the duplex pump.

Where the fuel oil line goes through the building, the is a valve held open with soft metal called a fusible link. If there is a fire in the powerhouse, the link will melt and shut off the fuel oil to the fire.

A fuel oil safety shutoff valve is placed in the fuel oil supply line. If the boiler shuts down for any reason, this valve will snap shut immediately.

The steam heaters bring the oil to the proper temperature before the oil is sent to the burner. The steam is controlled by a temperature regulator that has a thermal bulb strapped to the outlet of the steam heaters. As the oil gets colder, the thermal bulb cools, opening the steam valve more and heating the oil. As the oil gets too hot, the thermal bulb heats up, building up pressure from the boiling volatile fluid in the bulb through the line going to the top of the diaphragm. The pressure pushes down on the diaphragm in the temperature controller and starts closing the steam valve to the heaters. The condensate from the heaters is sent to waste. This temperature regulator is also known as an aquastat.



Courtesy Warren Electric

The electric fuel oil heaters use a thermostat to break an electrical connection to the heater when the oil gets too hot by using a contactor. A contactor is a spring loaded set of copper contact points that are pulled together by an electric solenoid. The solenoid acts as a magnet to pull the contacts together. When the thermostat shuts off the solenoid, the spring forces the contacts apart. This allows the sensitive thermostatic element to control a high amperage electric heater. The electric heater is used before steam is generated in the boiler.

The fuel oil meters are used to determine how much fuel oil is being used to generate the steam required by the building and equipment served by the boilers. The readings of the fuel oil usage meter is used in determining how efficiently the plant is running. The fuel oil regulator determines the firing rate of this mechanically atomized burner.

FUEL OIL DELIVERY

The following safety rules are to be followed when fuel oil is delivered.

1. A person must be assigned to watch the truck when the oil is delivered. Arrangements are made with the fuel oil company to assure that the driver will not unload oil until he has notified the boiler room.

2. The person assigned to watch the unloading checks the ticket to make sure that the proper amount and grade of oil has been delivered. The driver will either bring the amount ordered, or it will be metered into your tank. Either way the amount and grade of oil must be verified against what was ordered to prevent the tank from being overfilled or having the wrong oil delivered to the burners.

3. A wheel chock is put behind the tire to prevent the truck from rolling while the fuel is being delivered.

4. Stick the tank to get the fuel oil reading before the oil is dropped and then stick the tank immediately afterward to make sure the correct amount is delivered. Differences in the temperature of the oil will prevent the readings from being a perfect match, but they should be within 200 gallons.

5. A sample of the oil should be sent out to a lab to verify that the correct grade and guaranteed BTU value is being delivered. Even if you do not send the sample to the lab, you can visually check that the oil is the right grade. If you order #2 fuel oil and the driver gives you a jar of black tar, you know the company sent the wrong grade. If you ordered #6 fuel oil and the driver gives you a jar of a light brown fluid a little thicker than gasoline, you also know that he has brought the wrong fuel. Delivery of the wrong fuel does happen, and once it is in the tank you will not know until it is too late.

6. Oil spill containment socks should be at the truck when the driver is unloading. If the oil does spill, you immediately encircle the oil with the sock to prevent it from reaching the sewer.

7. If the oil reaches the sewer, you must immediately notify the Department of Natural Resources or your State Pollution Control Agency and the Environmental Protection Agency. Get the phone numbers and post them in the boiler room. The federal number is 1-800-424-8802. Do not try to get away without calling. They will track the oil spill to your facility and give you a large fine for not telling them.

8. Put Kolor Kut water finding paste on the end of the measuring stick when you dip the oil tank. When the paste comes in contact with water, it will immediately change from golden brown to bright red, marking the level of water. You will have to pump the water out and dispose of it with an authorized wastehauler. Gasoila is another brand.

NATURAL GAS

Natural gas is a colorless odorless fuel found deep in the earth, usually on top of oil deposits. The drilling techniques are the same as for oil.

Important facts to remember about natural gas are:

1. Heat content ranges from 900 to 1100 BTU's per lb. For examination test questions, 1000 BTU's per lb. is standard.

2. There is 20 cubic feet of natural gas to a lb. so there are 20,000 BTU's per lb. of natural gas. This is the highest BTU content of any of the common fuels.

3. Natural gas is mainly methane with a lesser amount of ethane.

4. Natural gas can either be sold by the cubic foot or else by a unit of measurement known as a "Therm". One Therm equals 100,000 BTU's.

5. Natural gas travels in the main pipeline from the well at 1200 psi. At the local utility the pressure is reduced to between 200 to 300 psi. The pressure is further reduced to 50 psi for the pipes running to under the streets to the boiler room. A reducing valve just outside or inside the boiler room reduces the pressure to 1 psi to 2 psi. Just before the boiler the pressure is reduced to 3 or 4 ounces of gas pressure. This equals about 1/4 psi.

6. Mercaptans are added to the natural gas as an odorant to give the gas its characteristic smell to warn of leaks.

ADVANTAGES OF NATURAL GAS

Natural gas has several advantages over other fuels. These include:

1. No preparation is needed before burning. No refining or preheating. It comes from the ground ready to be used.

2. There are no ash deposits so there is no expense in removing the ash as in coal.

3. If the burner is properly adjusted there will be no soot on the tubes as in coal or oil.

4. The delivery is simple since it comes through a pipeline so it cuts transportation costs.

5. The burner is easy to design and control.

6. Competitive rates on gas can be obtained by "wheeling". This is basically contracting with a gas producer to buy gas at the wellhead, and then paying the local utility to supply the boiler room through the local utility's pipeline. It is a little strange to think about since the gas bought from the gas producer's well is not necessarily the gas the purchaser gets at the boiler room, but the local utility and the gas producer get their fee and the purchaser saves money, so it works out well for all three parties. Since the contract stipulates that a certain amount of natural gas must be bought for the contract year, the amount of natural gas burned in a year must be known before signing the contract.

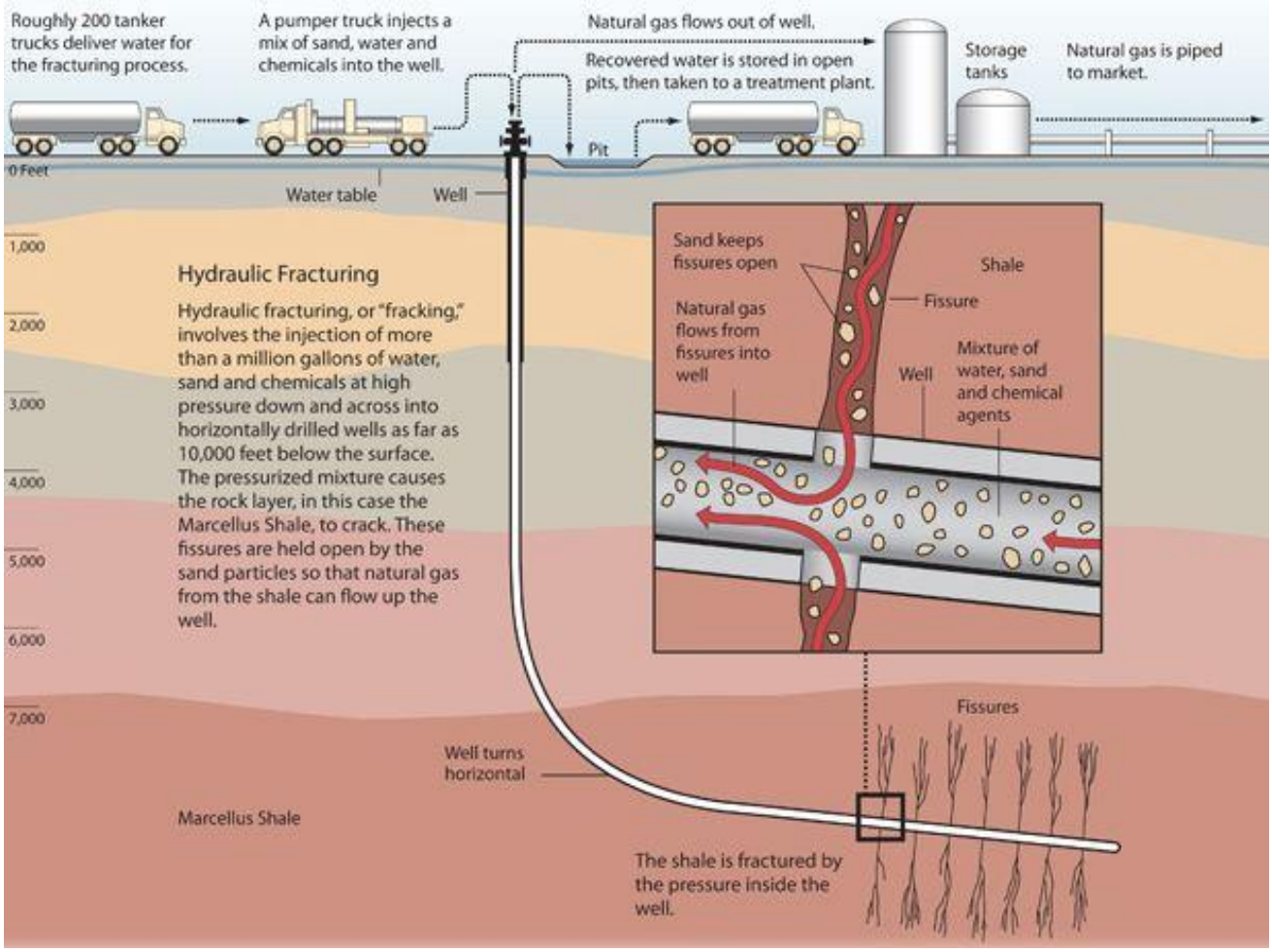
The disadvantages of natural gas are as follows:

1. It is usually more expensive than oil or coal. Sometimes cheaper gas prices can be obtained if oil or coal is used as a standby fuel.

2. The danger of explosion is much greater than for the other fuels.

Large House in Texas after Natural Gas Explosion

FRACKING


Roughly 200 tanker trucks deliver water for the fracturing process.
A pumper truck injects a mix of sand, water and chemicals into the well.
Natural gas flows out of well.
Recovered water is stored in open pits, then taken to a treatment plant.
Storage tanks
Natural gas is piped to market.
Pit
0 Feet
Water table
Well
1,000
2,000
3,000
4,000
5,000
6,000
7,000
Hydraulic Fracturing
Hydraulic fracturing, or "fracking," involves the injection of more than a million gallons of water, sand and chemicals at high pressure down and across into horizontally drilled wells as far as 10,000 feet below the surface. The pressurized mixture causes the rock layer, in this case the Marcellus Shale, to crack. These fissures are held open by the sand particles so that natural gas from the shale can flow up the well.
Sand keeps fissures open
Shale
Fissure
Natural gas flows from fissures into well
Well
Mixture of water, sand and chemical agents
Fissures
Well turns horizontal
Marcellus Shale
The shale is fractured by the pressure inside the well.

Fracking involves the high-pressure injection of 'fracking fluid' (primarily water, containing sand suspended with the aid of thickening agents) into a wellbore to create cracks in the deep-rock formations through which natural gas, petroleum, and brine will flow more freely. When the hydraulic pressure is removed from the well, small grains of either sand or aluminium oxide) hold the fractures open.

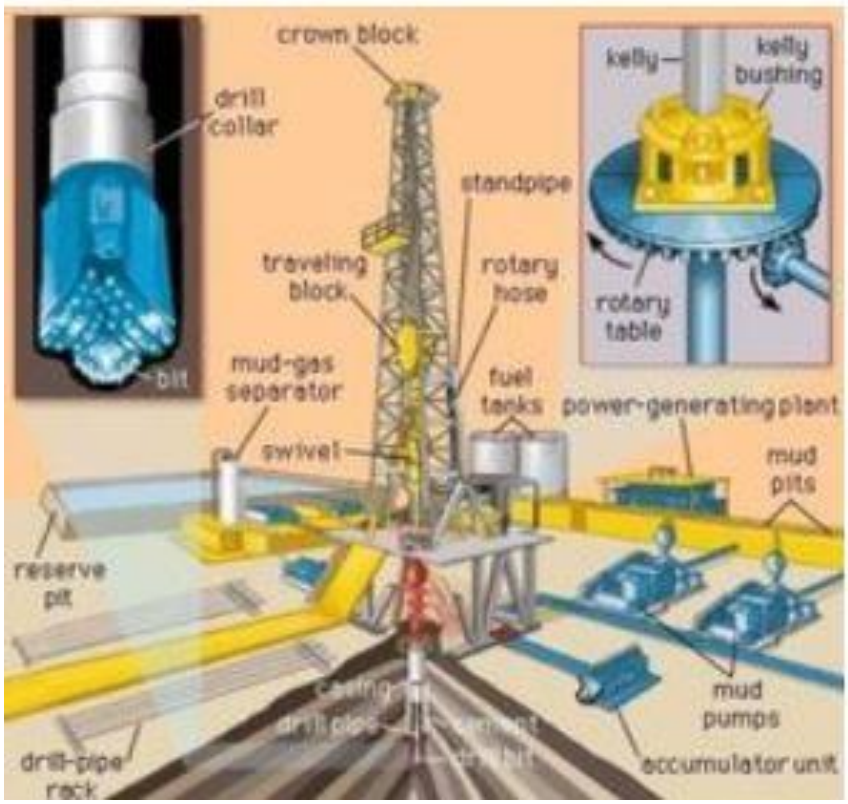
Hydraulic fracturing began as an experiment in 1947. Over 1 million "Frac jobs" have been done in the US. to date. A drilling resurgence since 2000 has transformed the United States into a leading natural gas producer and potential oil and gas exporter. The first step is to drill down to the sedimentary rocks, sometimes as far as ten thousand feet, then drill sideways for a mile or more. This horizontal drilling has been widely practiced since the 1980s to extract conventional oil and gas. Horizontal drilling and hydraulic fracturing have allowed producers to tap into large tight oil, shale oil, and shale gas deposits—some of which span multiple states—in the United States.

Earthquake activity is a concern because both the fracking process and the practice of injecting wastewater into deep wells can cause earthquakes, according to the U.S. Geological Survey. There

has been a dramatic increase in magnitude 3.0 or higher earthquakes in Oklahoma: There were over 140 such earthquakes in 2014, up from a pre-2009 average of just 1.6 per year.

Chapter 14 Questions

1. What is the difference between semi-anthracite and anthracite coal?
2. Which coal has the highest carbon content?
3. Which coal has the highest BTU value?
4. Which coal is known as brown coal?
5. What are the constituents of coal?
6. Which constituents of coal will burn?
7. Which constituents of coal are considered to be bad?
8. How do you conduct a proximate analysis of coal?
9. How is oil discovered under the earth?
10. What are the different grades of oil?
11. Which grade of oil has more heat per lb.?
12. Which grade of oil has more heat per gallon?
13. Which oils must be preheated before use?
14. Why do they bury fuel oil tanks?
15. How many BTU's per lb. does bituminous coal have?
16. How many BTU's per lb. does #6 fuel oil have?
17. How many BTU's per lb. does natural gas have?
18. How many cubic feet are in one lb. of natural gas?
19. How many BTU's are in a cubic foot of natural gas?
20. Why is natural gas known as the ideal fuel?
21. Why are both electric and steam heaters used to heat fuel oil?



Chapter 15

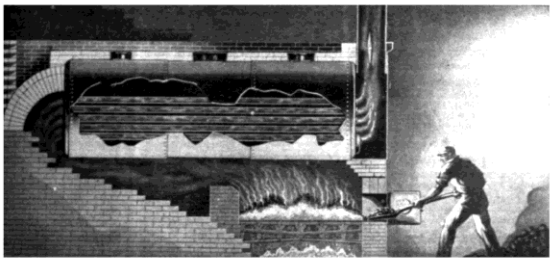
FUEL BURNING EQUIPMENT

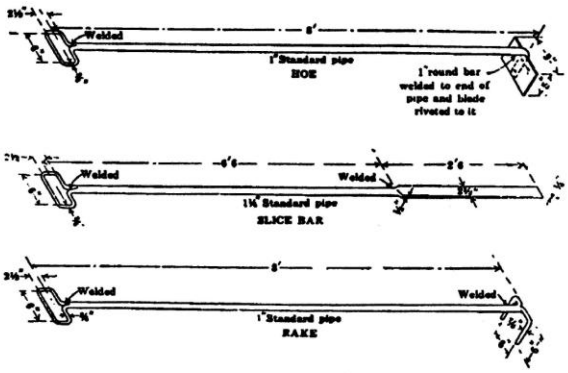
There are many methods of burning fuel efficiently. Hand firing, mechanical stokers are used for solid fuels. Different types of burners are used for oil and gas.

HAND FIRING COAL

1. The tools used in hand firing coal are the wheelbarrow, the shovel, the slice bar, hoe, rake, and a lazy bar if the boiler has a large grate.

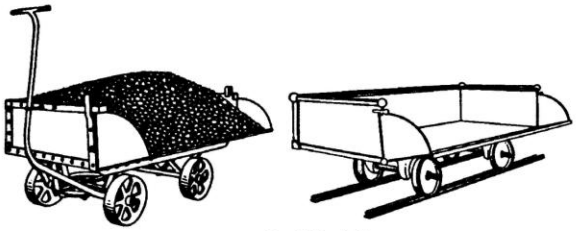
The Operator will load the wheelbarrow with coal and then dump it in front of the boiler far enough from the front so that the Operator can stand in one spot, dig in to the coal pile and swing the shovel of coal into the furnace in one smooth motion without having to move his stance. The coal is thrown in an arc with a slight flip of the tip of the shovel at the end of the throw to distribute the coal evenly over the grate. Another method is to hit the bottom of the shovel on the bottom frame of the firing door at the last instant of the throw.





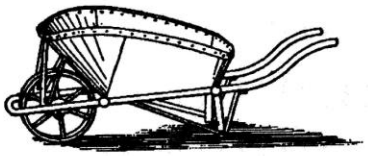
Hand firing tools

Coal Shovel

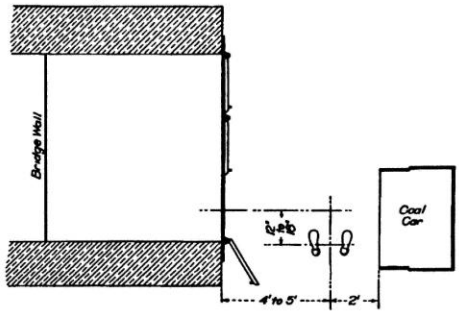


Steel Coal Cars

Coal cars for hand firing



Coal Wheelbarrow



Correct position for hand firing coal

2. Starting the fire (boiler water at normal level and the boiler is ready to fire). The entire grate is covered evenly with three inch or larger lumps so that the finer particles will not drop through the holes in the grate. Dry wood, twigs and shavings are placed on top of the coal. Oily rags or newspaper are placed on top of the wood and a match starts the newspaper or rags on fire. The fire will burn from the top down. Do not use a volatile fluid like gasoline or lighter fluid on the newspaper or rags. The draft damper to the chimney should be open and the ash pit doors open so that a draft of air can be drawn in to feed the fire. As the coal catches fire, throw on a little more coal until the bed is burning briskly and then adjust the damper and ashpit doors to provide the steam pressure needed without smoking. Sometimes coal is tempered by spraying water on the coal before firing for more uniform burning.

Operator firing a stationary locomotive boiler

3. Hand Firing on stationary grates

Anthracite coal should be spread evenly in small amounts and fed into the furnace regularly. The actual bed of burning coals should not exceed 2 to 3 inches, but as you throw more coal on the fire the total bed depth may reach from 14 to 16 inches before cleaning. When burning rice coal, the bed should not be over 9 inches thick. Rice coal is the same as #2 buckwheat. Since anthracite is a free burning coal you should not break up the bed with the hoe or slice bar. Grates for burning anthracite coal have smaller openings for air than do grates for bituminous coal due to the fusing together of burning bituminous coal that blocks the air openings.

Bituminous coal has a fuel bed of burning coals from 4 to 10 inches deep. The fire should be kept level by placing coal only where the bed is getting thin so that a level bed is maintained. Throw small amounts of green (unfired) coal into the furnace at regular intervals; between 5 to 8 minutes between firings. Stirring of the fuel should be avoided but it cannot be helped if the coal ash melts and fuses into clinkers that block the flow of air through the grate. The slice bar must then be used to break up the clinkers. Due to the volatile gasses that are distilled from bituminous coal, smoke can result if these gasses are not burned completely before leaving the furnace.

To clean the fires you use the slice bar to "wing" the live coals over to the left side of the furnace. You then break up any clinkers and hoe the ashes out the firing door from the right side of the grate onto the floor. You then wing the entire burning fuel bed onto the grates on the right side that you just cleaned. You then remove the ash and clinker from the left side of the furnace out the firing door. Now spread the burning coals evenly over the grate and fill any thin spots in the bed with green coal.

To bank the boiler for the night, allow the fire to burn down to a minimum. Push the live coals back in the furnace against the bridge wall in a compact pile. Cover the coals with ash, close the damper almost all the way, close the firing doors and the ashpit doors completely. Coal has the ability to stay lit a long time with minimal oxygen.

MECHANICAL STOKERS

There are 6 reasons why mechanical stokers are used in the place of hand firing.

1. Supplying the fuel as needed to the furnace without opening the firing doors increases economy of operation because you do not have the large drafts of excess air blowing into the furnace as you add more coal. The coal burns more evenly and ash removal is taken care of without manually cleaning the fuel bed.

2. Not as many Operators are needed to handle the boilers

3. Low grade coals that could not be burned on a stationary grate can be successfully burned on a stoker designed to handle that grade of coal.

4. Less smoke is produced because the coal is fired continuously instead of every few minutes.

5. The amount of coal that can be handled in a furnace is increased. This increases the ability of the boiler to produce more pounds of steam per hour.

6. Preheated air can be supplied to the stoker to increase efficiency but the preheated air temperature is limited to 250 degrees Fahrenheit to limit damage to the stoker.

There are three general types of mechanical stokers:

1. Traveling grate and chain grate

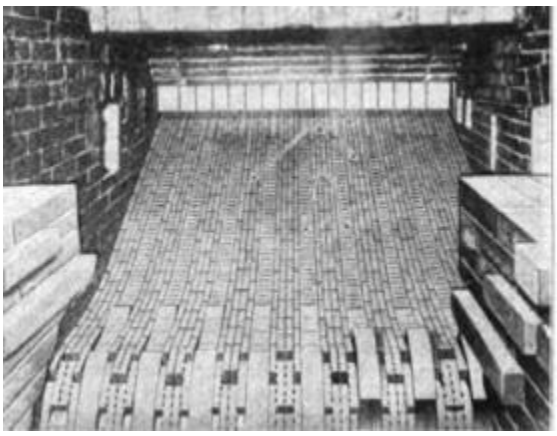
2. Overfeed (Spreader Stokers and Inclined Overfeed)

3. Underfeed stokers (Horizontal and Inclined)

TRAVELING GRATE STOKERS

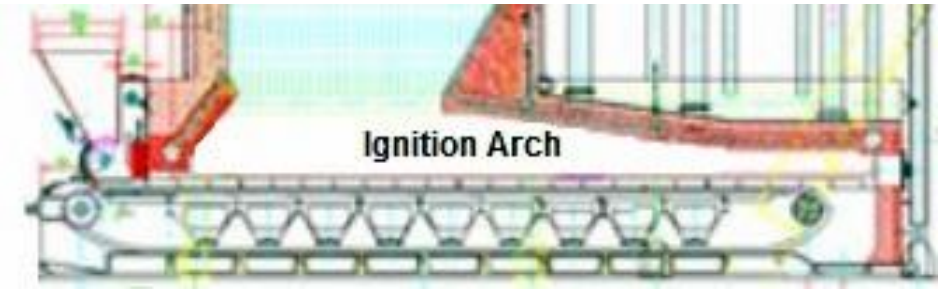
Traveling grate stokers are bar-grates that are lined in rows across the width of the furnace. These rows of bar grates are repeated down the length of the furnace. The rows are fastened to endless chains that rotate around sprockets at either end of the furnace. The coal is fed to the traveling grate from overhead bunkers that drops the coal into a hopper at the front of the boiler. An adjustable metal gate at the front of the boiler controls the depth of the fuel bed on the traveling grate. Depending on the type of coal, fuel bed depth varies from 2 inches to 7 inches. The speed of travel varies with the steam demand, 5 inches per minute or 25 feet per hour being normal and 18 inches per minute or 90 feet per hour being a maximum. At 40 feet per hour, small anthracite will burn at 30-40 pounds per square foot per hour. The air for combustion is admitted between the sprockets at the sides through windboxes that divide the compartments into different zones. Dampers at the windbox doors control the air for the combustion of the fuel as it moves down the traveling grate so that only ash should be left at the end of the grate. As the ash turns around the sprocket at the end of the grate the ash drops down into the ash pit. Only free-burning coal with a high ash content (6% or more) that does not cake can be satisfactorily burned on the traveling grate. As long as the coal meets these requirements it does not matter whether it is anthracite, bituminous, or lignite. The important factor is size. The coal should be 1 1/4 inch by 1 inch and smaller. Larger sizes would not burn completely before the grate has started to turn around the sprocket at the end of its travel. If the coal does not have a high enough ash content the burning coal could damage the grates. Traveling grate stokers need long rear arches to carry incandescent particles of burning coal forward to ignite the incoming coal.

CHAIN GRATE STOKERS

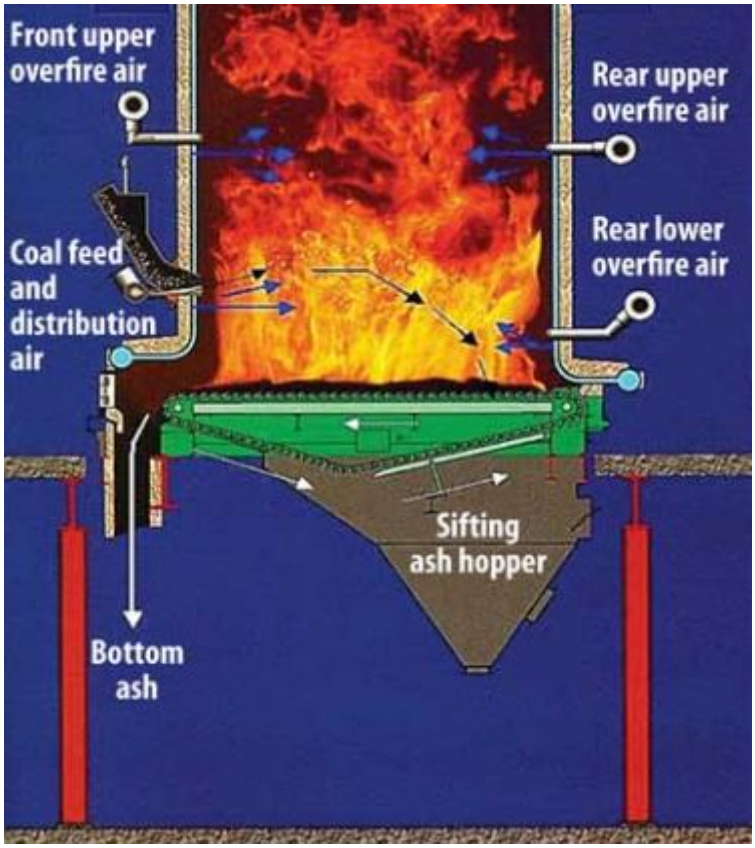


Chain grate stokers are identical in operation to the traveling grate, and all the requirements listed for the traveling grate apply to the chain grate. The main difference is the construction of the chain grate. Instead of having rows of bar-grates, the grates themselves are staggered links that are interconnected by rods to form an endless belt. As the links of the chain grate go around the sprocket they are better at breaking any ash that may be clinging to the grate than the traveling grate. Chain grate stokers burn small sizes of free burning bituminous coal.

Both the traveling grate and the chain grate stokers must have some type of ignition arch above the grate so that the incoming coal will ignite immediately. Almost all of these stokers have forced draft fans.



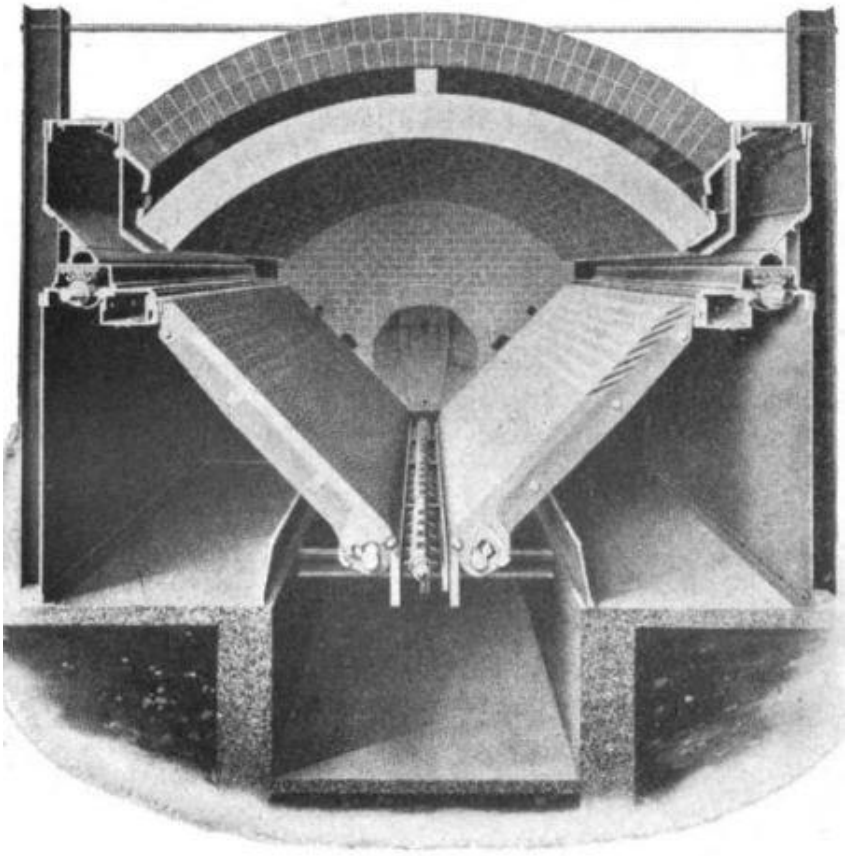
SPREADER STOKERS



A spreader stoker burns the widest variety of coal of any stoker. A spreader stoker uses a traveling grate, the difference is that instead of allowing the coal to flow on to the front of a grate that is moving toward the back of the boiler, the spreader stoker throws the small pieces of coal toward the back of the furnace and the traveling grate moves the coal toward the front of the boiler. The momentum of the paddle wheels that throw the coal send the heavier particles of coal to the back of the grate where they have longer to burn while the smaller particles drop toward the front where they burn to ash quicker. Fine coal dust can burn in suspension before they hit the grate. If the particles of unburned coal are carried out of the furnace with the draft, they can be captured by a centrifugal separator that collects the heavier particles. Cinder re-injection can then take the unburned particles and blow them back into the furnace through pipes that have over-fire air that helps assure complete combustion. Dust collectors collect the fine particles of ash that pass through the centrifugal separator. Due to the increase in draft resistance of the cinder and dust collecting equipment, induced draft fans are needed. The paddle wheel is mounted 2 to 3 feet above the grate. The spreader stoker responds quickly to variations in steam demand. The coal should be made up of different small sizes of coal but the fine particles should not exceed 25% of the total amount of coal.

INCLINED OVERFEED STOKERS

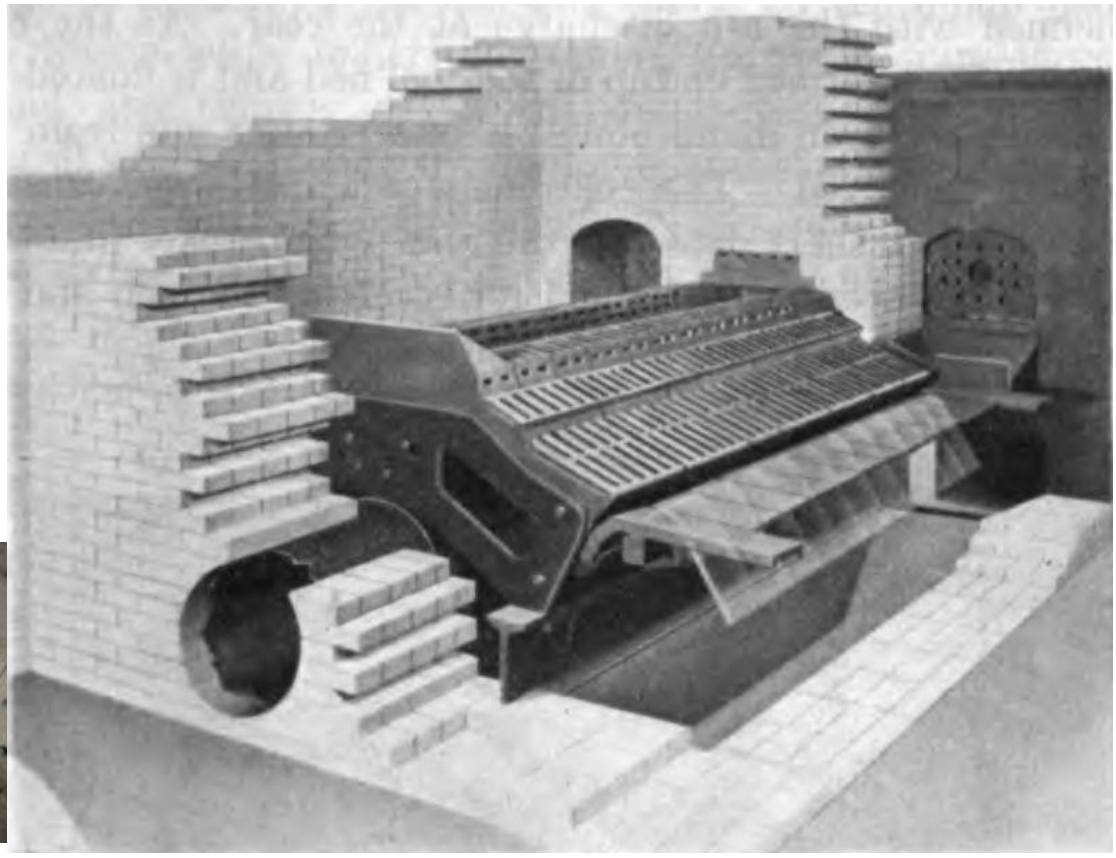
In the Inclined Overfeed Stoker the fuel is fed onto a dead plate from where it is moved by reciprocating grates and gravity down to the ash pit. The reciprocating grates alternate with stationary grates so that the coal is kept moving. Modern municipal refuse incineration boilers use a variation of the inclined overfeed stoker



MURPHY STOKER

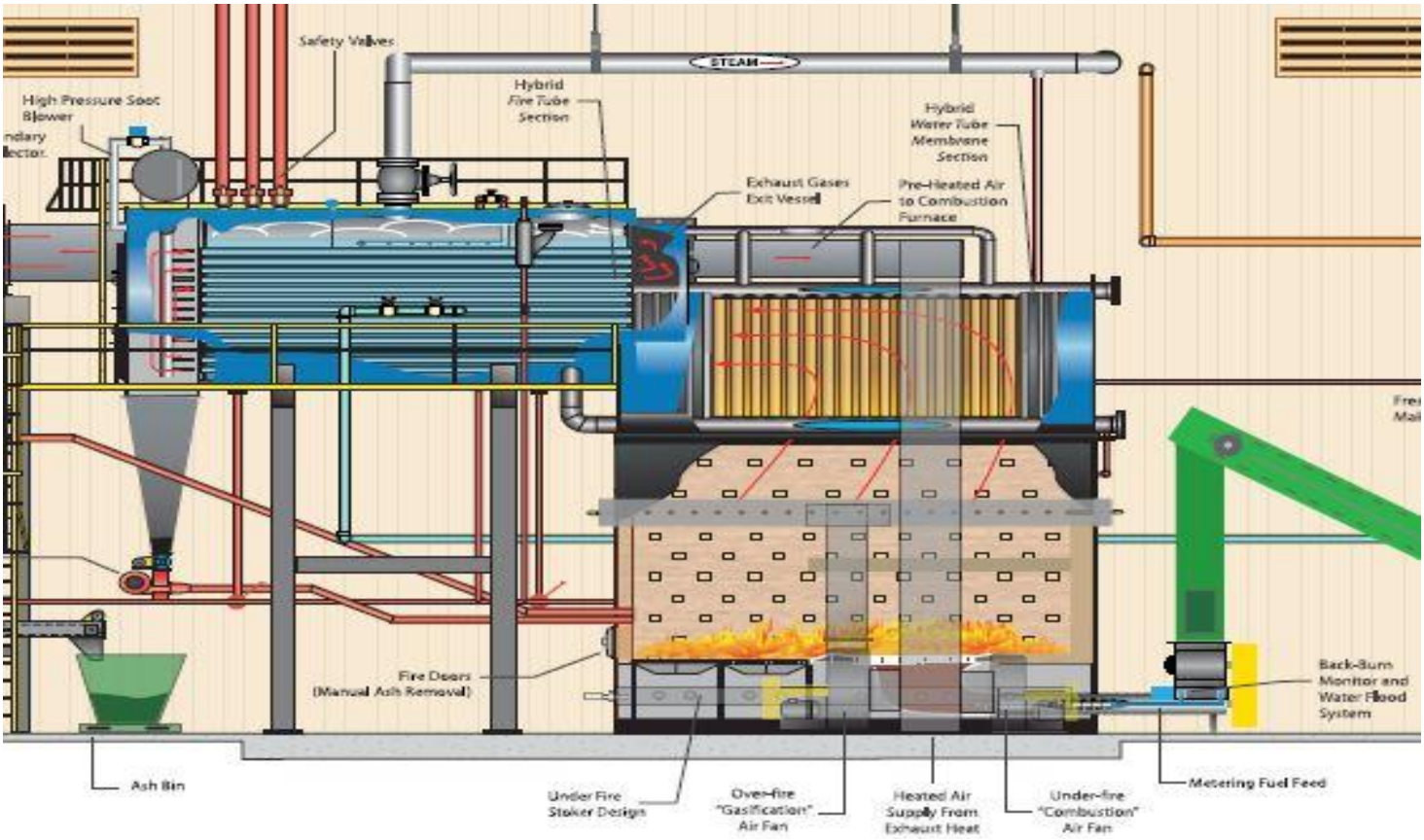
A variation of the Inclined Overfeed Stoker is the Murphy Stoker, which is usually installed in a "Dutch Oven" setting. In this stoker the coal is fed from two coal hoppers at the top of the furnace, one at either side. The coal travels down from the hoppers by a "stoker box", which is driven by rack and pinion gearing by a steam engine. The coal then sits on a dead plate which is cooled by an air duct directly below the dead plate. The coal then travels down the sides toward the bottom of the "V" that the furnace forms. A clinker grinder at the bottom keeps the clinkers from building up in the bottom of the furnace. The top of the "V" has an arch of firebrick over the furnace, an air space, and another arch of ordinary red brick over the firebrick. The air space formed by these two arches is used to preheat the incoming air. The furnace grate consists of alternating movable and stationary grate bars. The fixed grate has ribs to allow air to enter under the burning coal. "Bearer Bars" hold the bottom of the "V" and are made hollow so that the exhaust from the steam engine can keep it cool and blow exhaust steam on the clinker grinder to soften the clinkers and keep the clinker grinder cool.

HORIZONTAL UNDERFEED STOKERS

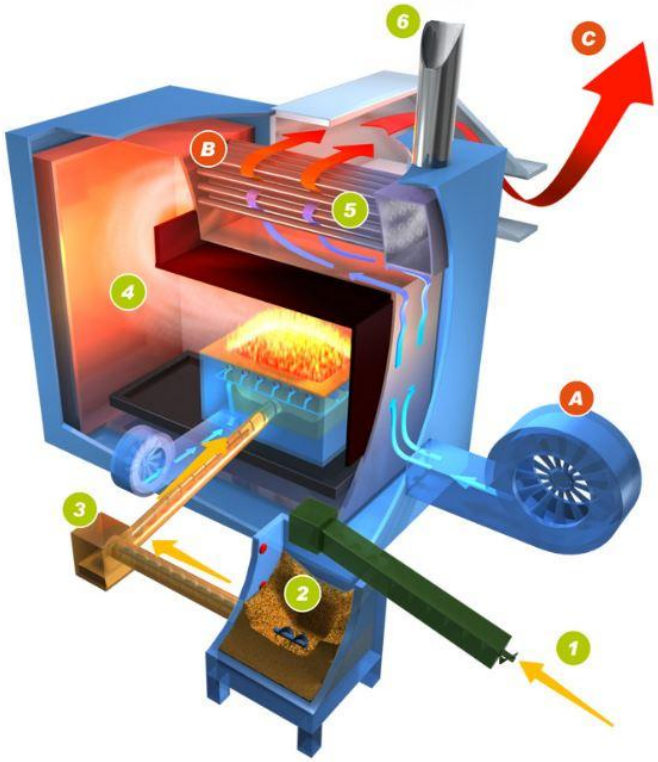


Courtesy Detroit Stoker

The coal is fed into hoppers at the front of the boiler either from overhead bunkers or by hand. The coal drops down into a trough at the bottom of the stoker and is pushed into the furnace by rams, pushers or screws that force the coal underneath the burning coal. The coal that is on top of the trough is then pushed onto the grates by the force of the coal that is being introduced into the furnace by the rams, pushers or screws. The trough is known as the retort and the grate or more correctly the air openings in the grate are known as tuyeres (pronounced Twee Urs). In the horizontal underfeed stoker the bed of fuel has a rounded top of burning coal that thins in depth as it moves toward either side. The coal on the grates turns to ash as it reaches the dump plates on either side of the retort and the ash is dumped periodically by allowing the dump plates to swing down on their hinges and drop the ash into the ash pit below the furnace. The green coal that is being pushed into the retort is turning to coke as it gets closer to the top of the fuel bed as the volatile gasses are being distilled off and burned. Horizontal underfeed stokers agitate the fuel bed by the action of the coal being forced up from the bottom and the rams reciprocating back and forth. Never allow the coal to burn down into the retort. Underfeed stokers need forced draft fans. The forced draft windbox pressure in a single retort underfeed stoker is 2 inches of water. Underfeed stokers can operate at up to 400% of their normal rating.



Underfeed stokers have had a resurgence in popularity with the interest in burning Biomass like wood chips, refuse, and Bagasse. Companies like Hurst Boilers have designed several types of furnaces and boiler adaptations in order to burn alternate fuels. Screw conveyors feed the fuel from underneath while forced air through the tuyeres provide the primary combustion air the above example.



TYPES OF FUEL OIL BURNERS

1. Mechanically atomized
2. Steam Atomized (inside and outside)
3. Air Atomized (inside and outside)
4. Rotary Cup

Mechanically atomized fuel oil burners use oil under pressure to atomize the oil into a fine mist, driving off the volatile gasses to ensure quick flame ignition and proper combustion.

The mechanically atomized burners have the oil pumped to them at a pressure of 75 to 300 psi with 200 psi being about average. Only enough pressure to ensure complete combustion with a minimum of smoke should be used. Pressures on recirculating mechanical atomizing oil burners have gone as high as 1000 psi. #6 fuel oil will be heated from 180 to 220 degrees at the burner. A Peabody burner gun consists of a tube within a tube. The fuel oil travels down the center tube of the gun and out a small orifice at the end. The sprayer plate at the end of the gun (which is about the size and thickness of a nickel) has 4 tangentially cut slots that give the oil a spinning motion as the oil leaves the gun. This breaks the oil into a fine spray that can be ignited. Any oil that cannot be forced out through the orifice is sent back through the space between the inner and outer tube and from there back to the storage tank.

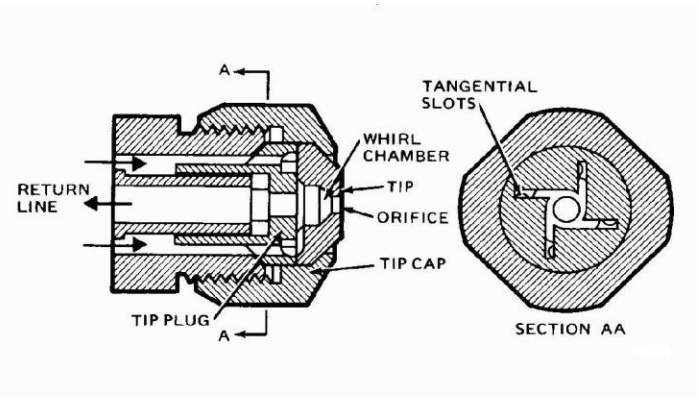
This particular type of mechanical burner depends upon oil pressure and orifice size to control capacity. This means that it has a small turn-down ratio, which is the difference in the amount of fuel handled from high fire to the lowest fire possible is very small. To control steam pressure with the steam demand with this type of burner you must either:

1. Increase or decrease the supply oil pressure at the pump governor, not the burner

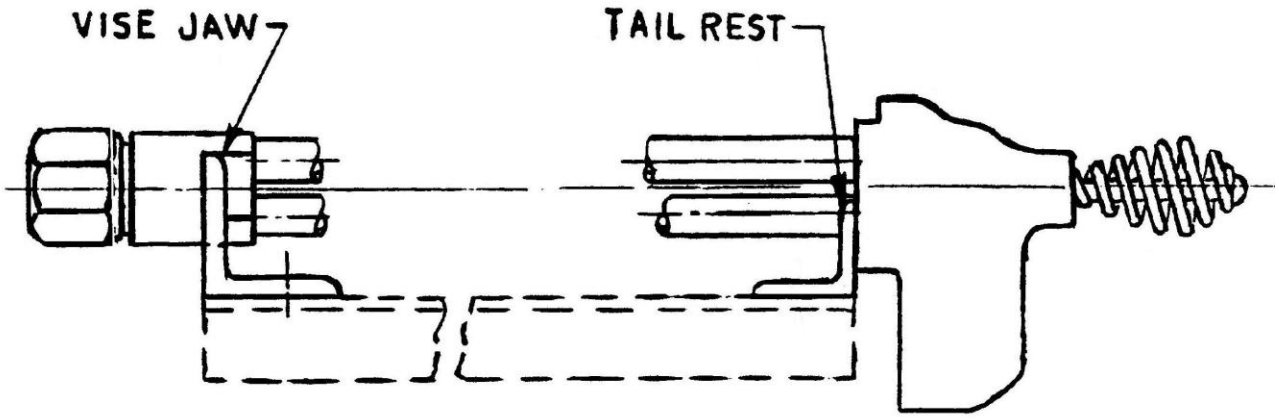
2. Cut in and out burners in a multiple burner boiler

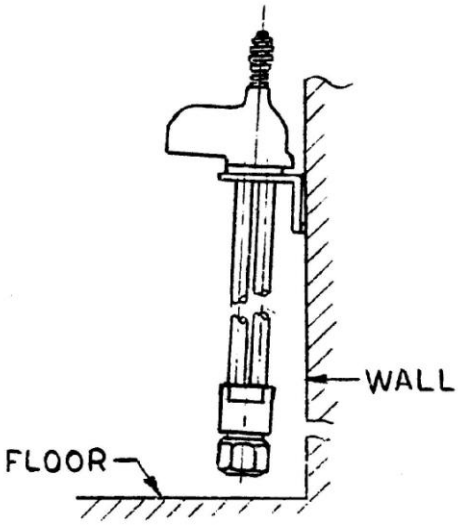
3. Replace the gun with a spare gun that has a larger or smaller orifice plate

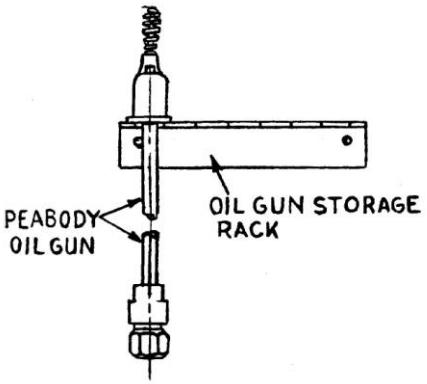
In order to increase the turn-down ratio, Mechanically atomized burners have been developed that use movable rods inside the inner tube with a cone shaped end that can be moved back and forth to control oil flow, or a system that controls supply pressure and return pressure simultaneously so that a constant pressure is held at the burner while the amount of fuel to the burner varies with the load.



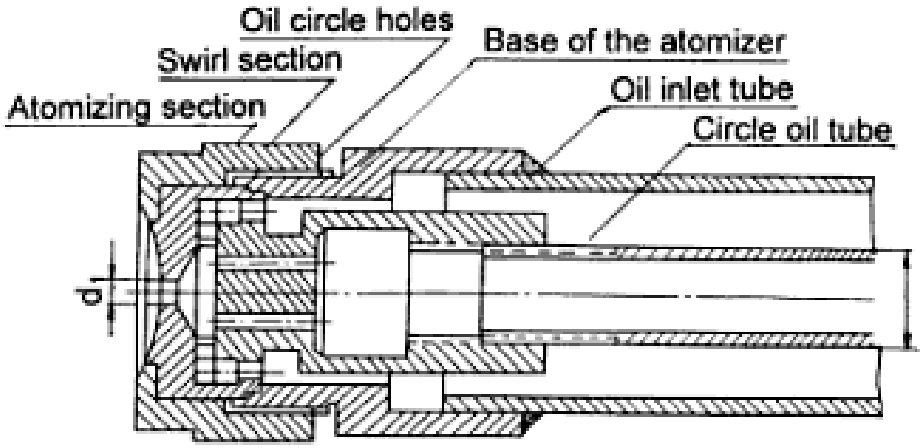
RECIRCULATING NOZZLE FOR A MECHANICAL-ATOMIZING OIL BURNER.







Burner guns that are not being used should removed immediately from the furnace or else the oil will bake on the tip and be difficult to clean. If the shut-off valves do not close off tightly, oil can continue to drip in the furnace and cause an explosion hazard. Burner guns should be cleaned as soon as possible by dipping the end of the gun in kerosene to soften the deposits, and then taken apart and cleaned with a piece of hardwood and a soft rag. Never use any metal on the finely polished burner sprayer plate because if it is scratched, it will not atomize the oil correctly and will become useless. Important points to remember about mechanically atomized oil burners are:



Cross section view of a return oil inner circle type atomizer

1. Mechanically atomized oil burners can burn from 20 to 650 gallons of oil per hour. Single burner forced draft mechanically atomized oil burners are normally rated at 200 gallons of oil per hour.

2. The flame on straight mechanically atomized #6 fuel oil burners becomes unstable at pressures below 120 psi.

STARTING A PEABODY MECHANICALLY ATOMIZED OIL BURNER

1. Make sure water level in boiler is at lower third of sight glass to allow for water expansion as boiler heats up.

2. Open the vent on boiler.

3. Open bypass valve from main steam header to between main steam valve and non-return valve on the boiler being warmed up.

4. Open the drain on the steam line between the main steam valve and the non-return valve.

5. Make sure oil pressure is around 200 psi, the pump is running normally, the oil temperature is around 200 degrees for #6 fuel oil. (these are only given as an example, the temperatures and pressures will vary with the oil and the plant).

6. Turn Master Burner Switch on

7. Set controller on Pre-purge

8. Start Induced Draft Fan

9. Start Forced Draft Fan

10. Make sure auxiliary interlock is on

11. Open the valve on the burner and press the bypass button to warm up the burner lines

12. Remove the bypass block on the burner that is in the center and put the gun in the center position

13. Open the valve to the gas pilot

14. Push the start button.

15. When the green light is lit, the gas pilot has been proven.

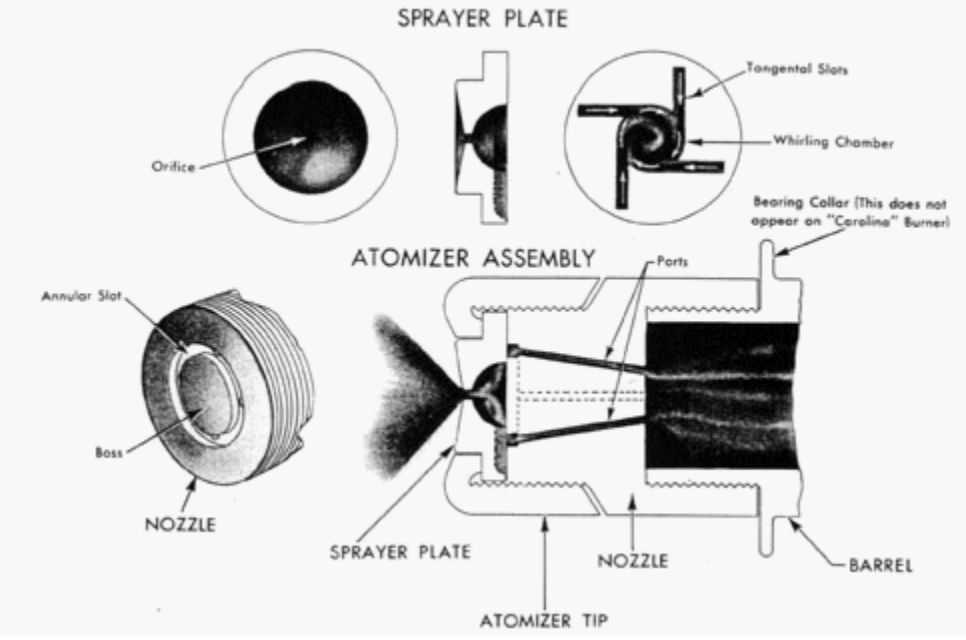
16. When the red light is lit, open the burner oil valve and the oil will ignite.

17. After the oil has lit, open the air register.

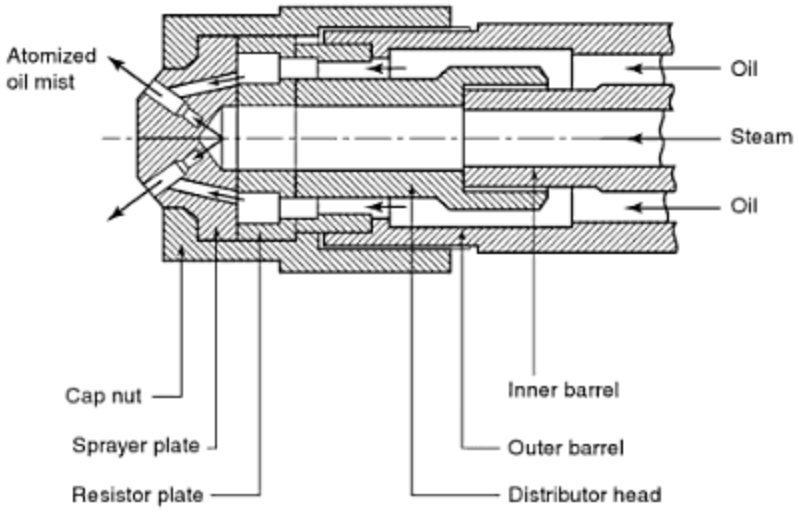
18. Adjust the boiler master controller for a positive pressure on the windbox.

The fuel oil goes through a bypass block at the burner while the oil is being heated. When the oil is sufficiently hot the block is removed burner gun is inserted.

Note that this procedure is for one specific installation. Each Boiler Room May have a different procedure.



STEAM ATOMIZED OIL BURNERS



Steam atomized oil burners use steam at 25 psi or more to break the oil into small drops. The physical action of the steam hitting the oil plus the expansion of the steam help atomize the oil. There are two basic type of steam atomized oil burners, the inside mix and the outside mix. As the name implies, the inside mix burner mixes the steam and oil just inside the burner tip before it is discharged into the boiler furnace. Depending upon the tip design, the flame can either be flat or conical.
The outside mix steam atomizer uses steam to shear the oil into small drops just as the oil is leaving the burner tip.

Important points to remember about steam atomized burners are:

1. The inside mix steam atomizing oil burner uses between 1 to 3% of the steam generated by the boiler to atomize the oil.

2. Outside mix steam atomizing oil burners use between 3 to 4% of the steam generated by the boiler to atomize the oil.

3. Steam atomized burners use 1 to 5 pounds of steam per gallon of oil burned.

4. Full load oil pressure ranges from 100 to 150 psi. The advantage is that it does not have as high a pressure as the mechanically atomized types.

5. Steam pressure is usually kept higher than oil pressure by 25 psi.

6. Compressed air for atomization or mechanical burners are sometimes used to provide start up capabilities for the steam atomized oil burner until sufficient steam has built up in the boiler. A combination burner would start on natural gas.

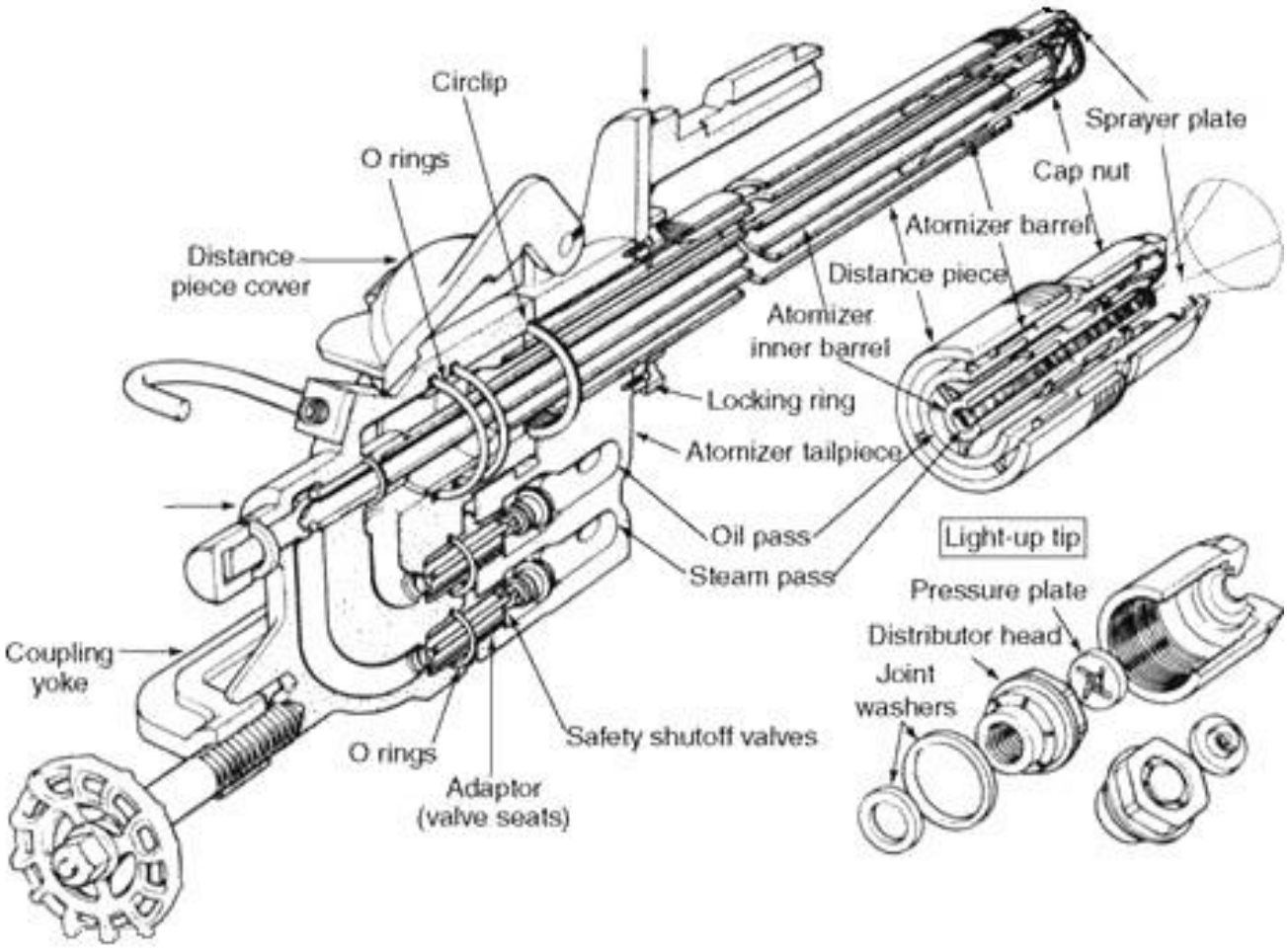
7. Steam atomized oil burners use 15% excess air.

8. Steam atomized oil burners have a turndown ration of 8 to 1

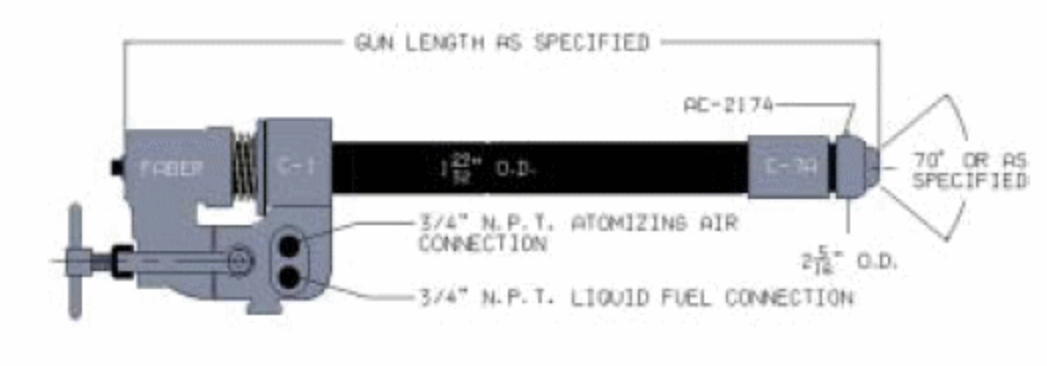
9. Steam atomized oil burners maximum capacity is around 250 gallons per hour.

10. Outside mix steam atomized oil burners are less likely to clog the nozzle than inside mix oil burners

11. Outside mix steam atomized oil burners require lower oil pressures than the inside mix burner to operate correctly.



AIR ATOMIZED OIL BURNERS



Air atomized oil burners are very similar to steam atomized oil burners in construction. The difference lies in the use of compressed air from 2 to 150 psi rather than steam. The advantage of the air atomized oil burner over the steam atomized oil burner is that it can start the boiler without having a supply of steam. The disadvantages are the added electrical cost and the cost of maintenance of the air compressor.

Important points to remember about air atomized oil burners are:

1. The burner uses from 2 to 7 cubic feet of air per gallon of fuel oil.

2. The turndown ratio is around 8 to 1.

3. They use about 15 to 25% excess air.

4. The air atomized oil burner's maximum capacity is around 530 gallons per hour.

5. Low pressure air-atomized burners use air pressure from 1/2 to 2 psi in large quantities.

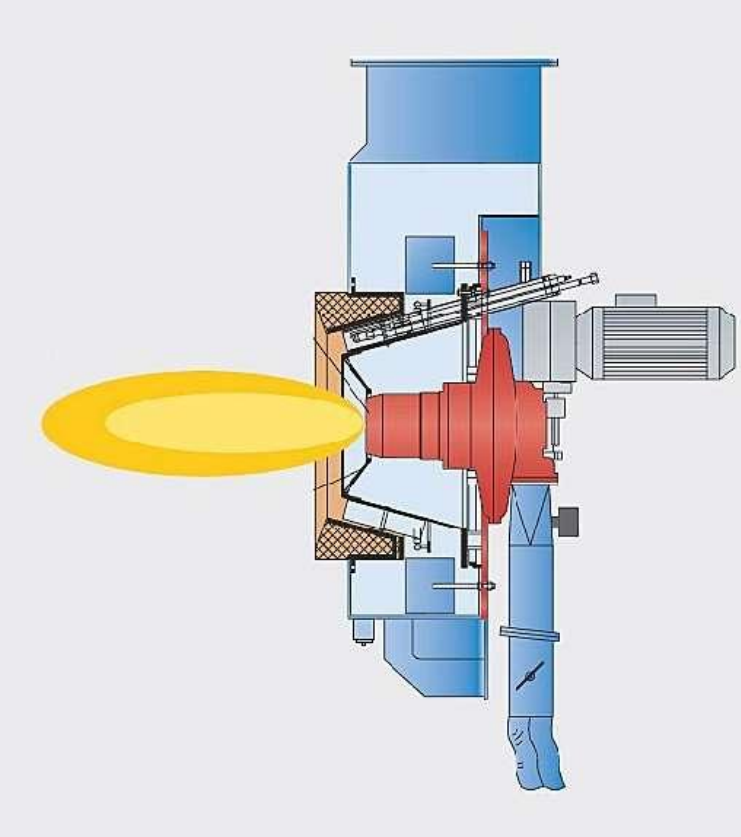
6. Low pressure air-atomized oil burners are inside mix.

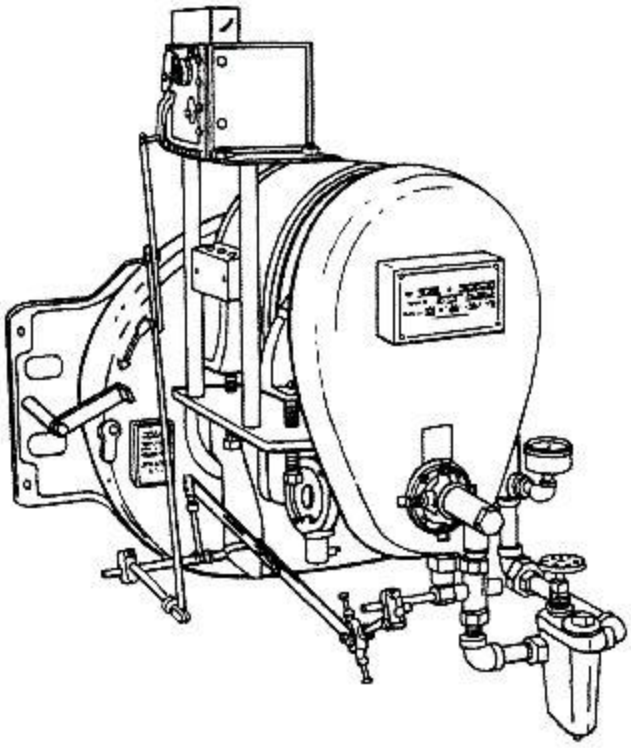
7. Low pressure air-atomized oil burners burn #2, #4, and #5 fuel oil.

8. High pressure air-atomized burners used compressed air at 25 to 150 psi. They have the highest operational cost of all burners due to the high cost of producing high pressure compressed air.

9. High pressure air-atomized oil burners can be used with the same nozzles used for steam-atomized oil burners.

ROTARY CUP OIL BURNERS





The rotary cup oil burner operates by spinning the oil out from the inside of a polished cup. As the thin film of oil leaves the edge of the cup, high velocity air from the fan around the outside of the cup breaks the hollow cone of oil into fine drops. The combination of the centrifugal force of the spinning oil and the air hitting the oil atomize the oil. The rotary cup and the supply fan are driven by a motor at the end of the shaft, making a very compact unit. Oil is delivered through the hollow shaft to the cup. The oil pump is usually driven by a worm gear connected to the burner shaft. The vanes on the outlet of the fan give a spinning motion to the air opposite the direction of the oil cup to help atomize the oil.

Important points to remember about the rotary cup oil burner are:

1. The speed of the shaft and cup is between 3450 to 6000 rpm

2. The turn down ratio is around 4 to 1

3. The burner uses 20 to 25% excess air

4. Refractory is needed in the furnace to help support combustion.

5. The rotary cup burner can burn different grades of oil without needing major changes to the burner.

6. Different size cups can be used to vary the flame pattern. The flame is adjusted so it does not hit the rear of the combustion chamber.

7. The rotary cup burner can be belt driven as well as direct drive.

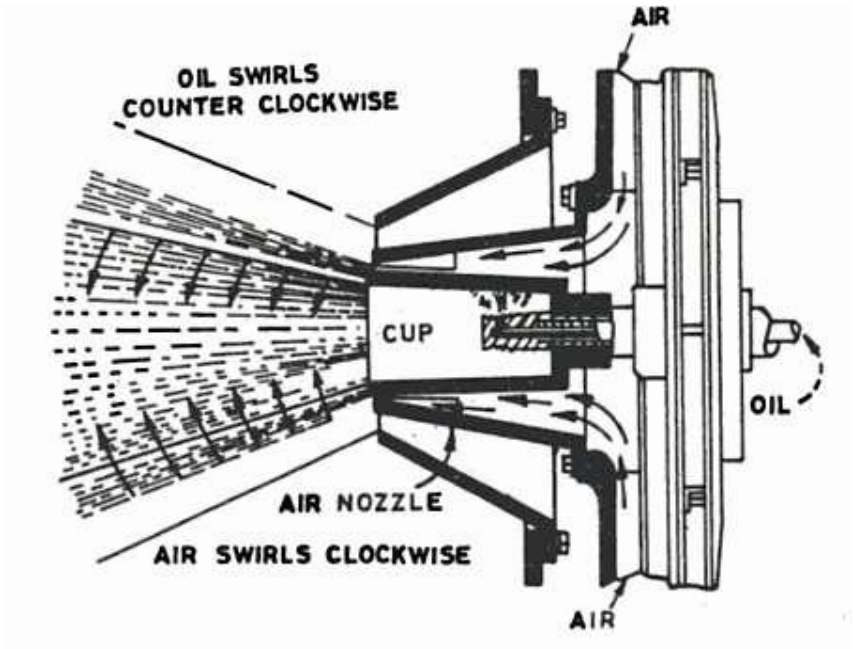
8. The rotary cup oil burner do not usually burn more than 100 to 150 gallons of oil per hour.

9. The fire starts several inches from the edge of the cup.

10. Never use steel tools or a steel wire brush to clean the carbon deposits from the cup. They will damage the finish and the oil will not atomize correctly. Soak in kerosene and use wooden scrapers and rags to clean.

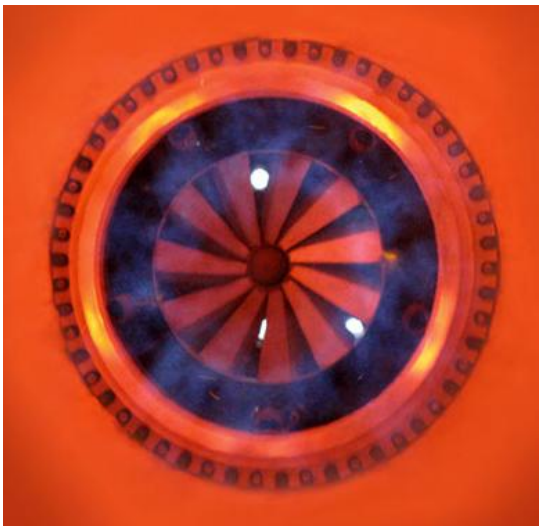
11. If the oil temperature is too low, smoke will result.

12. If there is water in the fuel, sputtering and sparking will result.



GAS BURNERS

Burners for natural gas are simple in construction. The atmospheric burner uses low pressure gas with enough velocity to pull air needed for combustion along with the gas stream by creating a suction as the gas flows from an orifice in the burner. They also mix the gas with the air to ensure combustion.

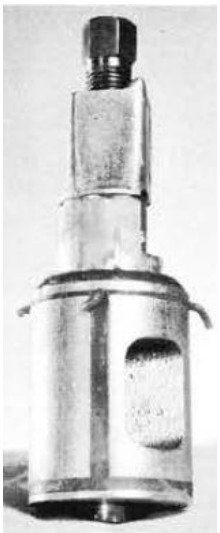


A gas burner that operates from a few ounces of gas pressure to 4 psi is known as a low pressure gas burner. A high gas pressure burner will operate up to 35 psi. Gas flames will vary with the burner.

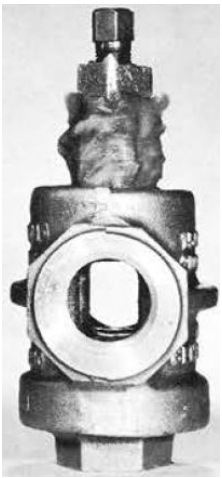
The gun burner uses a long tube to direct the gas into the furnace. The gas is released from nozzles at the end of the gun. Air from a forced draft fan will add turbulence to the gas to ensure complete mixing. A slotted round shield is placed around the end of the gun so that the high velocity air does not blow out the flame.
The ring burner uses a metal ring similar in size and shape to a bicycle inner tube. Holes are distributed evenly around the ring on the side toward the combustion chamber. Air from the forced draft fan causes a swirling motion to the flame as the gas is burned.

Gas Trains have special plug cock shut-off valves. These have special grease fittings to pump grease around the valve to stop any leaks. The grease comes in sticks, cans, and grease gun tubes. You turn the hex head at the top to push more grease into the valve. If the hex head is at the bottom, you remove it and push in another grease stick. The valve is designed not to put too much grease in the valve. Overflow will come out the top. Whenever the boiler is off, turn the gas cocks off and back on to make sure the valves are free.

Grease sticks, grease can, and tube for grease gun.



grease slots in valve

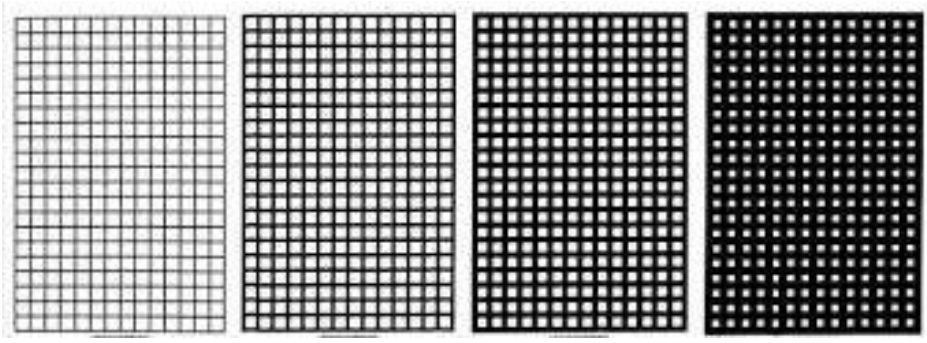


grease overflow

Boiler rooms need outside air for combustion. You need a permanent opening to the outside of one square inch for of opening for every 2000 BTU/hr input for a burner's combustion air. There are different air temperatures and volumes in the summer compared to the winter. The boiler's combustion controls should be recalibrated every 6 months to account for these differences. These are now EPA rules.

RINGLEMAN CHART

The Ringleman Chart is used to determine how dense the smoke is exhausting out the chimney. The Ringleman card is taken outside and by looking at the smoke with the chart extended, you can determine the smoke density on a scale from 1 to 5; 5 being pure black.



Chapter 15 Questions

1. How do you start a fire in a hand fired coal boiler?
2. How thick should the burning bed of anthracite coal be in a hand fired boiler?
3. Should you agitate the bed of anthracite coal between firings?
4. How big is rice coal?
5. How thick should the burning bed of bituminous coal be in a hand fired boiler?
6. Should you agitate the bed of bituminous coal between firings?
7. How do you bank a hand fired boiler?
8. Why are mechanical stokers used?
9. What is the depth of the fuel bed on traveling grate stokers?
10. What size should the coal be on a traveling grate stoker?
11. Why does size play such an important role in the complete burning of coal on a travelling grate stoker?
12. What is the difference in construction between a travelling grate and a chain grate stoker?
13. What sizes of coal are needed to burn successfully on a spreader stoker?
14. How are fine particles of unburned coal taken care of in a spreader stoker?
15. How does an inclined overfeed stoker work?
16. How does an underfeed stoker work?

Chapter 16

AUTOMATIC COMBUSTION CONTROL

One hesitates to use the word "Automatic". It has become a buzzword that is used to relieve an individual of responsibility.

"How was I supposed to know that the boiler was stuck in high fire without any water?" "I had it in automatic!"

It is as if by turning the knob to the magic word on the control panel a Genie appears to operate the boiler, leaving the Operator free to pursue more leisurely activities.

Stop and think what Automatic Combustion Controls are trying to achieve. Imagine you are hand firing coal for an HRT boiler. After you have thrown in the fresh coal and leveled the bed, you shut the firing door and crack the ashpit door to allow air to enter the bed of hot coals from underneath. You want just enough air to stop the chimney from smoking, not only because of the pollution, but because smoke means unburned carbon is leaving the stack. Unburned carbon wasted means more coal will have to be tossed in by you. Opening the ashpit doors too wide means that too much fresh air is getting in, burning the coal more quickly but cooling the exhaust gasses and lowering the steam pressure. This means more trips to the coal pile with the wheelbarrow and more back-breaking work. shoveling coal onto the grate. It will not take too long before you figure the exact position of the ashpit door opening to allow you the most rest. That is combustion control. You feed just enough oxygen to ensure complete burning with the most heat being utilized to create steam.

Now let's consider a gas boiler with a simple on-off control. When there is a drop in steam pressure, and the thermostat is below setpoint, there is a Bourdon tube just like the one in the steam gage is located inside a device called a pressuretrol. When the bourdon tube contracts from lack of steam pressure, a glass tube filled with mercury tips and makes a connection between two open prongs inside the glass tube. The mercury, being a great electrical conductor, completes the circuit and starts the ignition sequence for the gas burner. You might get a "Call for Heat" light on your control panel. After a fan start and prepurge, it starts the pilot ignition sequence, proves that the pilot is lit, and then opens the gas valve for the main flame and to start making steam in the boiler. Because the burner should be set for its maximum efficiency, the right amount of air to mix with the gas is preset. When the steam pressure rises to the pre-set limit, the bourdon tube expands, the little glass tube tips the other way, the mercury runs away from the prongs and the boiler shuts down after completing a post purge cycle. What a great system. Everybody should have one. The disadvantage is that the boiler can short cycle if the pressuretrol hits its setpoint before the thermostat is satisfied.

The next step up the Controls ladder is the Positioning system. It is like the on-off system but it has a set of linkages hooked to a rod called a jackshaft that controls both the gas valve and the amount of air entering the furnace simultaneously. The On-Off system is hard on boilers because the constant heating and cooling of the boiler metal. In heating systems the air vents let corrosive oxygen in the air back into the system once the steam has condensed in the radiator. The positioning system has the advantage of modulating the fire to better suit the demand. The boiler runs longer and does not short cycle like the on-off cycle if the pressuretrol reaches its cut-out before the thermostat is satisfied.

If the combustion controls are examined carefully, it will be seen that they are simply pressure switches, relays, and other electrical, pneumatic, or electronic devices that make and break switches, or send air pressure or milliamp signals to move actuators in response to changes in the boiler pressure and steam and airflow. It cannot be stressed enough that the Boiler Operator must know how combustion control systems function in order to ensure proper safe operation of the boilers. If the proper documentation is not in the boiler room, call the manufacturer and get it. Gather every scrap of information you can about every control device on the boiler. Make notes and drawings of the valve and linkage positions of the different controls at different firing rates. Mark the linkage attachment points on the rod with indelible ink. How can it be known if the linkage has slipped if there are no marks of where it was attached in the first place?

Use Garage Door Spray to lubricate the positioning type cams and linkages. It does not attract as much dirt as other oils.

Boiler Controls have 5 functions that they coordinate:

1. Steam Pressure
2. The proper amount of fuel needed for combustion
3. The proper amount of air needed for combustion
4. Removal of products of combustion from the furnace as they are formed.
5. The regulation of the feedwater supply so that it keeps a normal operating water level in the glass

The feedwater regulator is not a part of the boiler burner control, but if it is a combination feedwater regulator/low water cut-out, then it will shut the burner off if a low water condition occurs.

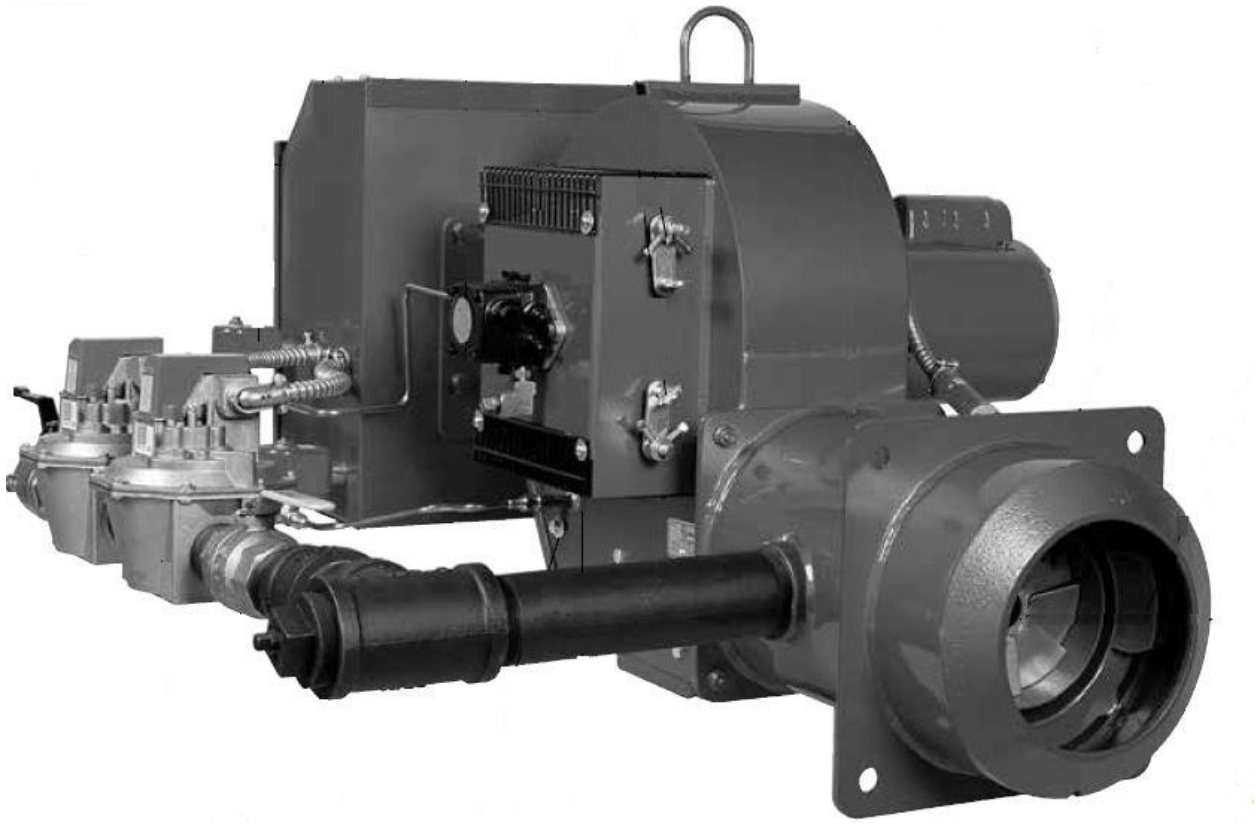
There are three main types of automatic combustion control, namely:

1. On-off
2. Positioning
3. Metering

ON-OFF CONTROL

On-Off is the simplest type of automatic control. It senses the steam pressure through pressure switches sometimes known as pressuretrols and sets of contacts make or break the firing circuit. A typical application would be a low pressure heating system where the boiler's setpoint is adjusted to run at 10 psi and the boiler actually operates between 8 and 12 psi. When the steam pressure drops to 8 psi the burner starts and when the steam pressure hits 12 psi the burner shuts off. The burner does not modulate and so the fuel, combustion air, and outlet damper are set for best combustion when the burner is firing. The pressure between the 2 psi lower than setpoint and the 2 psi higher than setpoint that the boiler actually operates at is called the deadband. The purpose of the deadband is to prevent the burner from starting and stopping too quickly, which is called short-cycling. Note that when on-off control is used the actual steam pressure may drop below the pressure that starts the burner or go above the pressure that shuts off the burner, in our example the steam pressure could drop below 8 psi or go above 12 psi. The reason is that if the building is calling for more heat, the burner may not be able to instantaneously provide enough heat to prevent the steam pressure from dropping below the cut-in point of the burner. In the same way, if the building is satisfied as the burner reaches its setpoint; the steam pressure could overshoot the cut-out point of the burner.

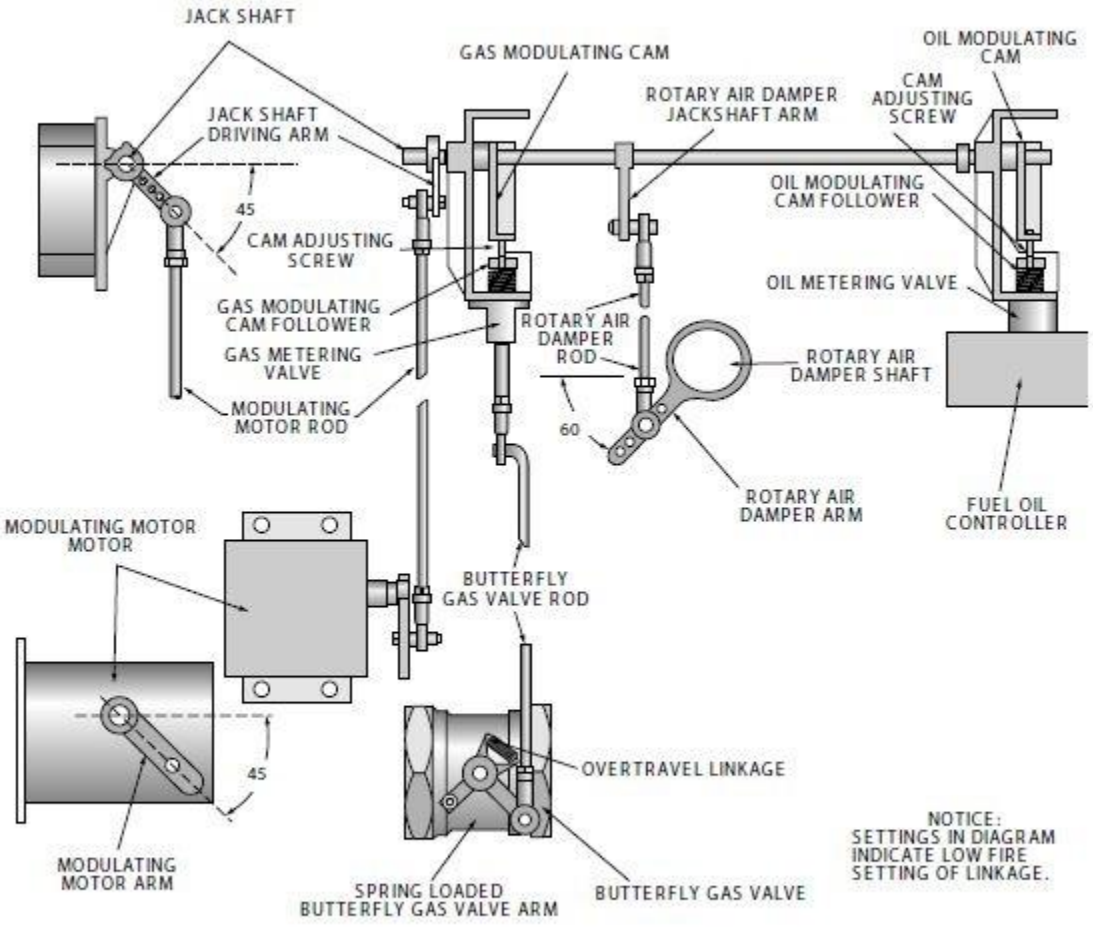
A variation of the on-off control is the High-Fire--Low-Fire--Off control that has a low fire setting that the boiler will go to as the steam pressure is reaching its setpoint. This will keep the steam pressure more constant with less cycling of the burner. Most controls of this variety will have a way to hold the burner in low fire on start-up in order to evenly heat the boiler up with less stress on the metal.



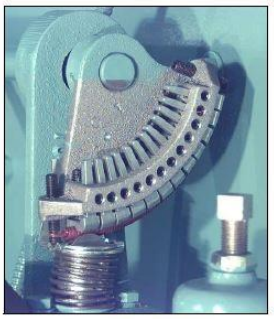
C Power Flame Burner (Courtesy PB Heat LLC)

POSITIONING CONTROL

The positioning control operates the fuel valve and the fan damper together so that as the steam pressure falls, the fuel valve opens to increase the firing rate and the fan damper is linked mechanically so that the proper amount of air is fed into the furnace to match the new firing rate. For each position that the fuel valve goes to, the fan has a position that is going to give maximum combustion efficiency. Some burners use set screws placed along a curved section of metal so that the setscrews can be turned in or out to adjust the relationship between the fuel valve and the fan damper at each position of firing. A long tightly-wound spring is stretched over the set screws and a roller follows the cam shape that the spring and setscrews have formed.



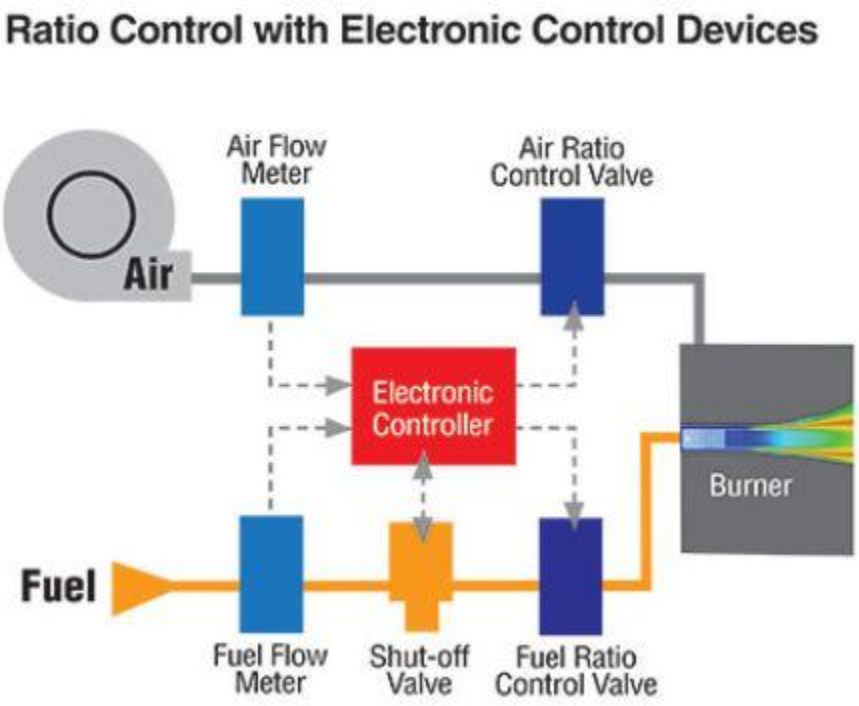
Complete Linkage Assembly, Combination Gas and Oil

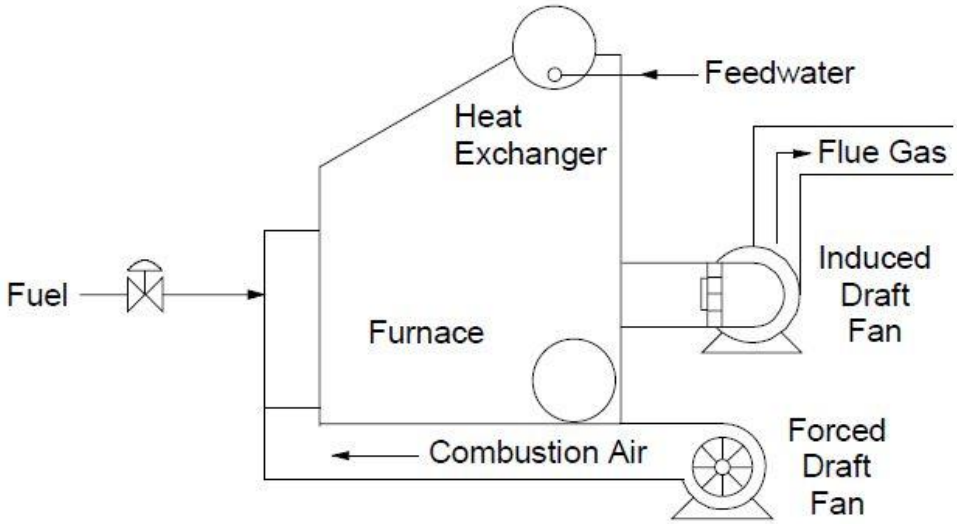


Gas Modulating Cam

METERING CONTROL

In the metering type of combustion control, the fuel flow and air flow are actually measured so that combustion can be fine-tuned to its maximum efficiency. Steam pressure is kept much closer to setpoint when a properly adjusted metering control is used. When forced draft and induced draft fans are used, furnace pressure is kept slightly below atmospheric by adjusting the dampers. This is known as balanced draft.





INDUSTRIAL BOILER FLAME SAFETY CONTROLS

Industrial boiler flame safety controls are electric or electronic devices that control the sequence of events that allow a burner to safely operate. In a gas or oil fired boiler those events are:

1. PrePurge
2. Pilot-Ignition Trial with Pilot Flame-establishing Period
3. Main Burner Ignition Trial with Main Burner Flame-establishing Period
4. Run Period
5. Postpurge
6. Shutdown

1. Prepurge is the amount of time after a call to start the burner during which the blower fan runs to ensure that all combustible gasses are flushed out of the furnace so that a furnace explosion will not occur. Four or five complete furnace volume changes of air are mandatory to satisfy insurance requirements. Typical Pre-purge periods range from 30 to 96 seconds.

2. Pilot-Ignition Trial which includes the Pilot Flame-establishing period is the time period that the programmer allows the pilot valve to be open before the flame detector is required to detect the pilot flame. This is usually 10 seconds. If the pilot is not proven within the 10 seconds, the burner will shut down, a pilot failure light will light on the panel and an alarm will sound. The burner will go into Postpurge to clear the furnace of any combustible gasses before shutting down.

3. Main Burner Ignition Trial which includes the Main Burner Flame-establishing period is the time period that the programmer allows the main valve to be open before the flame detector is required to detect the main flame. This is usually 10, 15, or 30 seconds. If the main flame is not proven within the chosen time period, the burner will shut down, a main flame failure light will light on the panel and an alarm will sound. The burner will go into Postpurge to clear the furnace of any combustible gasses before shutting down.

4. Run Period is when the burner has passed all start-up tests and the burner is in its normal running mode. This time period lasts as long as there is a need for the steam and could be hours, days, weeks, or even months in duration. The programmer timer is not turning during this time period.

5. Postpurge is the time that the fan blower continues to run after the demand for steam has been satisfied and the fuel valve has shut off or the Operator has manually thrown the shutdown switch to stop the burner. It is usually 30 to 96 seconds depending upon the furnace size because 4 to 5 furnace volumes of air must pass through the boiler before the blower will stop.

6. Shutdown of the burner occurs after Postpurge is complete.

Some other features of the flame safety controls must be discussed in how they relate to the 6 events described above. They are:

1. Timer Cycle
2. Recycle
3. Safe Start Check
4. Safety Shutdown or Lockout
5. Lockout Switch

1. Timer Cycle is the time required for the complete rotation of the timer in a programmer excluding the time the timer stops for high fire or low fire proving and for the run period. The most common timer cycles are 90, 120, and 180 seconds.

2. Recycle refers the process of a programmer going through another timer cycle in an attempt to restart the burner after a normal shutdown with no alarms present.

3. The Safe Start Check prevents the programmer from starting its cycle if a flame or flame simulating condition is present before Prepurge begins or during Prepurge. There is not supposed to be a flame present at the burner before the igniter has started and the pilot solenoid valve has opened to start the pilot. If the Safe Start Check does detect a flame before or during prepurge, something is wrong and rather than continue, the Safe Start Check will initiate the Safety Shutdown.

4. The Safety Shutdown or Lockout is the action of shutting off all fuel and igniters to the burner after an unsafe condition has occurred. You will need to have the condition that caused the shutdown corrected before the Lockout Switch can be successfully reset.

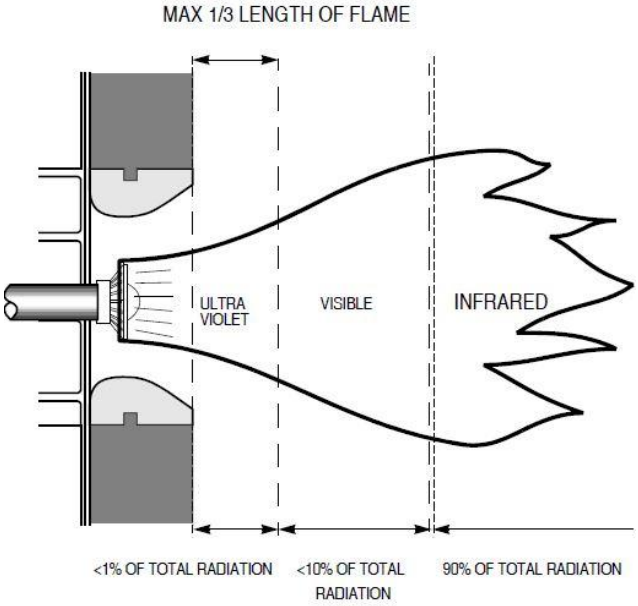
5. The Safety Switch or Lockout Switch is the time delay and manual reset that locks out the programmer when unsafe operating conditions occur. The manual reset must be pushed to allow the Operator to attempt to restart the burner. If the condition that caused the shutdown has not been corrected, the burner will go back into the Safety Shutdown or Lockout mode.

Some of the conditions that could cause the Safety Shutdown to operate are:

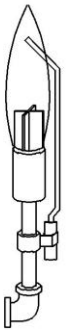
1. Failure of the pilot to ignite
2. Failure of the main burner to ignite
3. Loss of flame during the run period
4. Detection of flame or flame simulating conditions before or during prepurge
5. Opening a preignition interlock during prepurge (breaking an electrical circuit through a safety switch such as low gas pressure).
6. Opening of a lockout interlock during prepurge, ignition trials, or the run period (Usually an airflow switch which means that the Induced Draft or Forced Draft fan has stopped running).
7. Failure in the flame detection system (if a self-checking system is used).

The lockout switch of the Safety Shutdown has a small heater that will cause a bi-metal element to "pop" out the lockout switch which trips the electrical circuit. This is a method of providing the time delay necessary to give the pilot enough time to light before shutting down the burner. If this happens, the switch must be manually reset before the burner will attempt to ignite again.

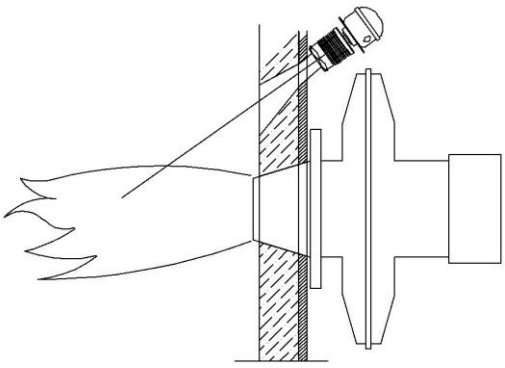
TYPES OF FLAME SENSING DEVICES



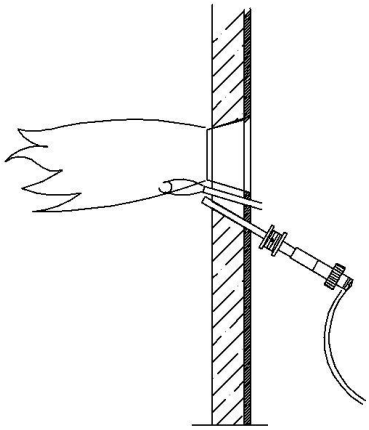
There are four different type of flame sensing devices used in industrial boilers. They detect different parts of the light spectrum, both visible and invisible The four types are:



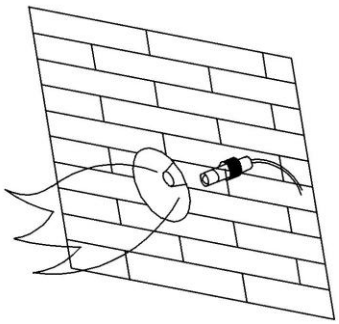
1. Flame Rod (flame rectification)



2. Rectifying Photocell



3. Infrared (Lead Sulfide)



Model C7012 is a solid state electronic flame detector used with Honeywell flame safe guard controls and amplifiers. It sense's Ultraviolet radiation produced by combustion of gas, oil or other fuels.

4. Ultraviolet

All flames have the following in common:

1. They produce heat.

2. The gasses from the products of combustion expand as the fuel burns.

3. Chemical changes occur to the fuel as it burns (for example, carbon and oxygen form CO2 as the carbon burns).

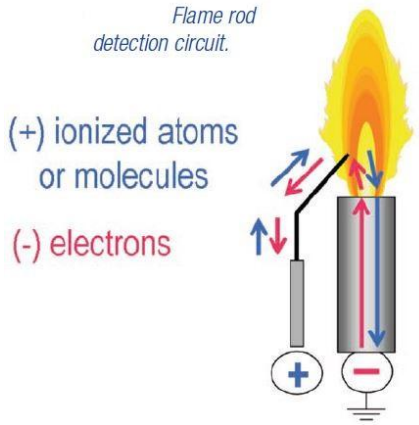
4. They produce light, both the visible light that we can see and infra-red and ultra-violet light that we cannot see.

5. The area in and around the flame becomes ionized (electrons are driven from their atoms) and will conduct electricity.

6. Flames "flicker" or pulsate in size and length.

Some of these six characteristics of flame are used by the flame sensing device to detect the flame and shut down the burner if there is an absence of that flame.

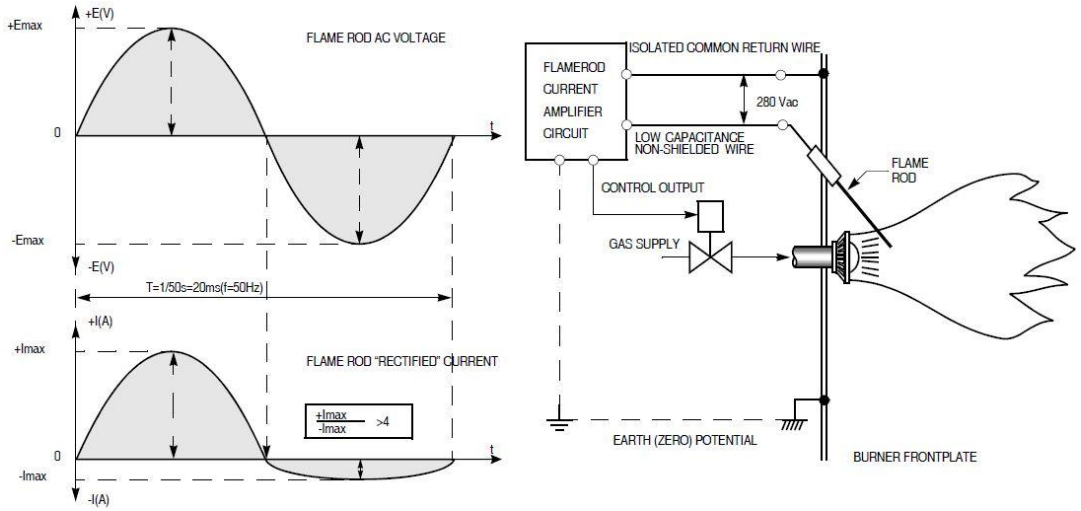
FLAME RODS



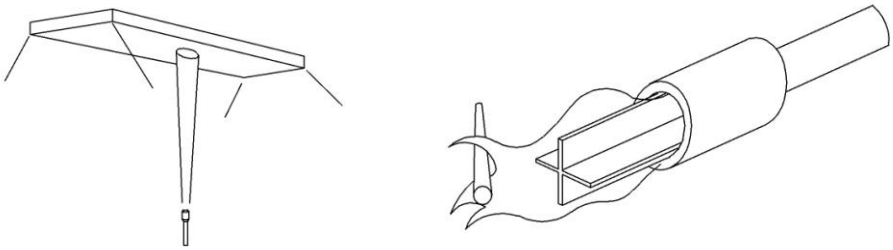
In the United States we use 60 Hertz alternating current electricity to power our electrical loads. As the revolving electromagnets in today's huge electrical generators move closer to and then away from the output wire in the circular coil that surrounds the electromagnet, power increases and decreases in relationship to that distance. When the revolving electromagnet or rotor has turned 90 degrees or 1/4 revolution from the output wire, power falls to zero or is at the same level as current in the ground. The power continues to build in a negative direction in relation to ground until it reaches its maximum at 180 degrees or 1/2 revolution. As the rotor continues to turn, the power is generated in a negative relationship to ground until the rotor has turned 270 degrees or 3/4 revolution. This is where the power is again at zero in relation to ground. The power then starts building in a positive direction in relation to ground until it again reaches its maximum power at the output wire. If you study the illustrations, you will see that this is where the Sine wave of AC power comes from as the power changes from positive in relation to ground to negative in relation to ground 120 times per second. The maximum power at the top is equal to the maximum power at the bottom and both parts of the sine wave produce equal amounts of useful power.

We have already stated that flame can conduct electricity. We could put two rods or electrodes of the same size with a space between them into the flame and allow the flame to conduct electricity across the rods. If the flame were to stop for any reason, the electrical circuit would be broken and the burner would shut off the fuel supply, preventing an unsafe condition. This was done in some early flame detectors but it was soon found that carbon deposits from the flame could bridge the rods and cause false positive readings.

This is when flame rectification started being used. Rectification means that you change the sine wave so that more power is generated in the positive direction than in the negative direction. The programmer can then be set up to recognize the higher power in the positive direction and allow the timer cycle to begin its sequence to start the burner. If the power becomes equal in both directions or if the circuit opens, the rectifying circuit will shut down the burner. This is much safer than just using the conductivity of the flame because now the flame rod cannot be fooled by carbon deposits.



How do we generate more power in the positive direction than in the negative direction? We still use two electrodes, but now we make the ground electrode or ground plate much larger, at least 4 times larger than the positive electrode. This causes much more current to flow in the positive direction (from the smaller rod to the larger ground rod or plate) than in the negative direction (from the ground plate to the rod).



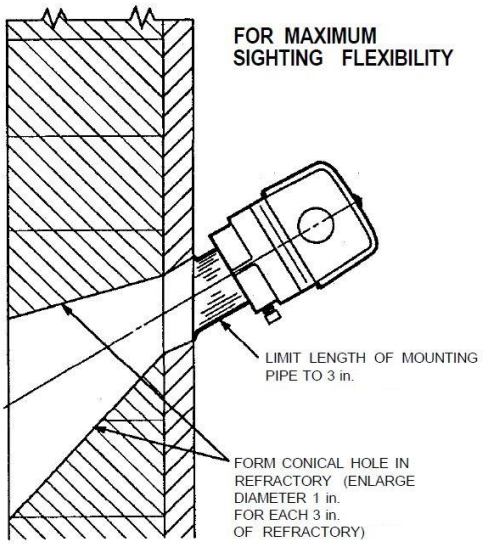
Let's see if the following example will help to illustrate this. Let's say you are sitting in a chair under a standard 2 ft. by 4 ft. fluorescent lighting fixture with a small flashlight in your hand. For purposes of this illustration we will assume that our fluorescent fixture is putting out an equal amount of light (electrons) as our flashlight. You point the flashlight at the fluorescent fixture and note the pattern that the flashlight forms on the fixture. Almost all the light from the flashlight hits the fluorescent fixture so if the fluorescent fixture were the ground plate, and our flashlight were the positive flame rod, almost all the electrons from our positive flame rod would hit the ground plate. Now let's reverse the situation. Most of the light (electrons) from our fluorescent fixture will miss the flashlight because it is so small in relation to our fluorescent fixture. Remember there are equal amounts of light from each source. Therefore there are many more electrons going in a positive direction than in a negative direction, and the sine wave shows a much more pronounced height in the positive direction.

Correct positioning of the flame rod must be done in order to insure that not only is the flame rod sensing flame, but it is sensing a strong enough pilot flame to ensure the smooth starting of the main burner. The flame rod should not be set directly above a pilot burner that is placed horizontally in the main burner. A small flame would rise straight up and cause the flame rod to allow the main burner to start sending fuel into the furnace that would not ignite immediately as it should.

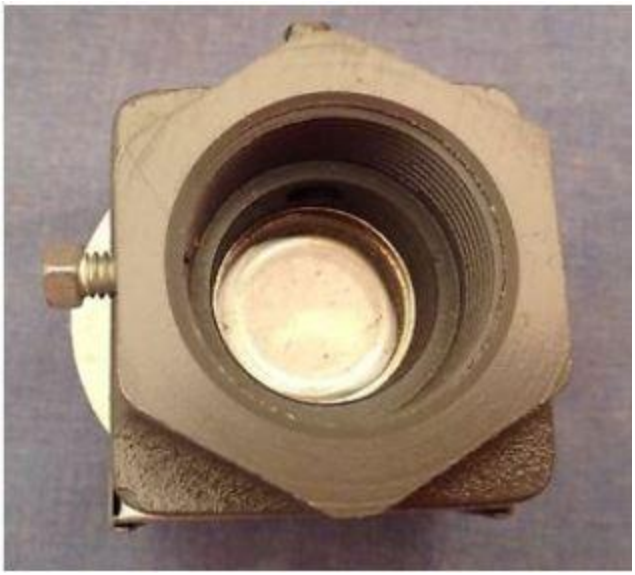
Flame rods are suitable for gas flames only. Oil flames are higher in temperature and could damage the flame rod.

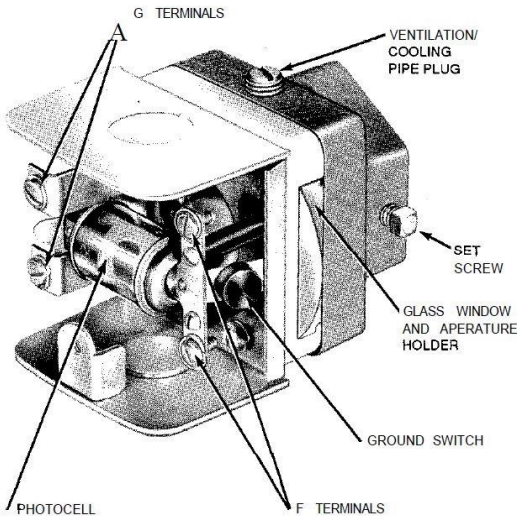
RECTIFYING PHOTOCELL

The rectifying photocell is a method of using the visible light that the flame produces to change the AC sine wave into a pulsating DC that the electronics of the programmer can use to tell if a flame is present or not. If a short circuit were to pass AC to the electronics, it would immediately shut down the burner.



The way the photocell works is that it uses a light sensitive material (caesium oxide) to coat the cathode or negative DC side of the photocell. The anode or positive DC side of the photocell does not have a light sensitive coating on it. Both the anode and cathode are surrounded in a glass vacuum tube. When the light of the flame strikes the photocell, electrons are driven off the caesium oxide on the cathode and create a conductive path for electricity between the cathode and the anode. Since AC power alternates between positive and negative in relation to ground, when the anode is positive, the negative electrons driven off the cathode will conduct electricity from the negative cathode to the positive anode. 1/120 of a second later when the AC reverses polarity, electricity will not flow from the positive anode to the negative electrode because the anode does not have the light sensitive material coating on it and the anode will not conduct electricity without that coating. The net result is that the electricity is traveling only from negative to positive just as DC electricity does.





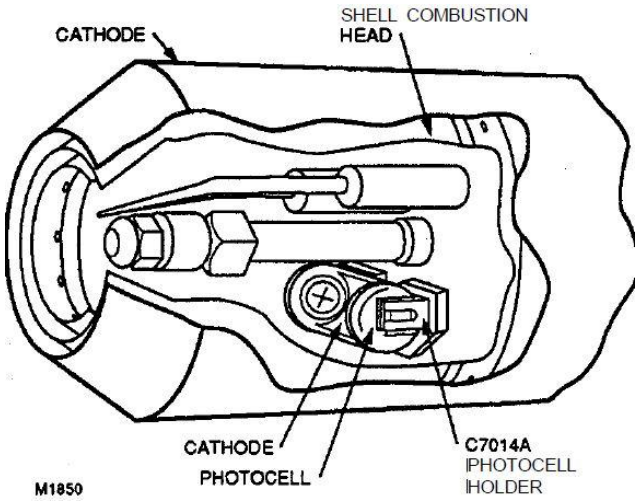
Rectifying Photocells are generally only used on oil burners because gas flames do not emit enough visible light to ensure satisfactory operation. There are four requirements for good rectifying photocell performance:

1. The cell must have a good view of the flame.

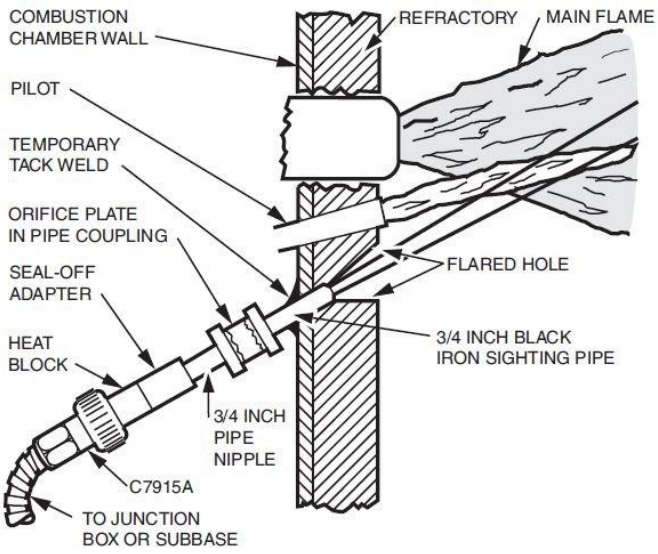
2. The cell must be protected from the light emitted by the hot refractory to prevent false positive readings.

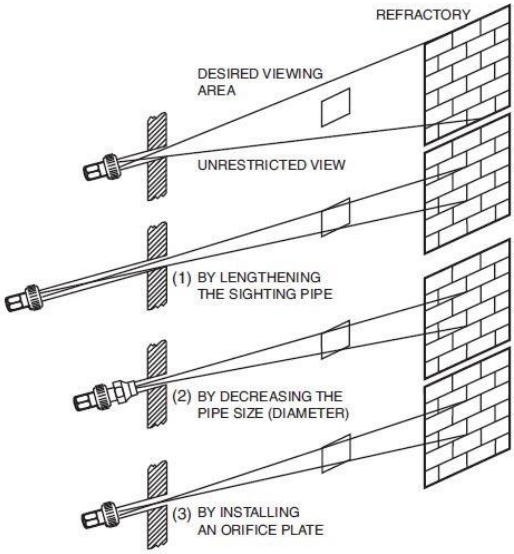
3. The cell must get no hotter than 165 degrees Fahrenheit.

4. A minimum of #14 copper wire with high temperature insulation must be used for the leads from the photocell.



INFRA-RED FLAME DETECTORS




REFRACTORY
DESIRED VIEWING AREA
UNRESTRICTED VIEW
(1) BY LENGTHENING THE SIGHTING PIPE
(2) BY DECREASING THE PIPE SIZE (DIAMETER)
(3) BY INSTALLING AN ORIFICE PLATE

Infra-red detectors use lead sulfide which is a material that has the property of losing resistance to electrical flow when it is exposed to the flickering infra-red radiation that a fire gives off, so an electrical circuit can be completed through the detector in the presence of a flame. Electrical current will not flow when the lead sulfide cell does not sense infra-red radiation. Infra-red detectors are good for either gas or oil flames because of the tremendous amounts of infra-red radiation given off by both types of flames. This type of detector will not respond to the steady infra-red radiation that hot refractory gives off. The disadvantage of the infra-red detector is that it can be fooled by the infra-red radiation that hot refractory can give off due to a phenomenon known as shimmer.

Shimmer is the fluctuation radiation that hot refractory will produce as it travels through the hot air, steam and smoke present in the furnace. If the sensor is not correctly placed, a false positive reading will result. If these fluctuations occur at the same frequency as that of a flickering flame, they will simulate flame and will hold in the flame relay after the actual burner flame has been extinguished.

A false negative reading can occur due to a phenomenon known as radiation saturation. If the hot refractory's infra-red radiation is strong enough, it can "blind" the detector to the pilot flame so that it cannot "see" the flickering flame of the pilot and instead it senses only the steady radiation of the refractory. In this case the pilot will refuse to light because it thinks that there is no actual flame present. Again, correct placement of the sensor will cure this problem.

Both of these problems will be minimized by aiming the detector at a portion of the refractory that is:

- as cool as possible.
- as far from the cell as possible.
- as reduced a field of view as possible

OPERATION OF INFRARED DETECTORS

Infrared detectors can be used with gas, oil, coal, or dual-fuel flames. Since more than 90% of the total flame radiation is infrared, these detectors receive ample radiation and can detect weak flames as well as flames of higher intensity. The lead sulfide cell used in the detector cannot distinguish between the infrared radiation emitted by hot refractory and the infrared radiation from a flame. Therefore, the infrared detection system includes an amplifier that responds only to the flickering characteristic of flame radiation and rejects the steady radiation characteristic of hot refractory.

Unfortunately, smoke or fuel mist within the combustion chamber can intermittently reflect, bend, or block the hot refractory radiation, thus making it fluctuate. This fluctuating action can simulate the flickering radiation from a flame, and infrared radiation may be present even after the refractory has visibly stopped glowing. Therefore, be very careful when applying an infrared detection system to be sure it responds only to flame. The sensitivity of the lead sulfide cell decreases as its temperature increases. Up to 125°F, the loss in sensitivity is negligible, but temperatures above this point must be avoided. Under normal temperature conditions (below 125°F, the life of the lead sulfide cell should be unlimited. The quickest check for excessive temperature is simply to grasp the detector—it should not be too hot to hold comfortably in your bare hand. Although the infrared amplifier will not respond to steady radiation, as produced by hot refractory, be careful to protect the infrared detector from hot refractory radiation because of two possible conditions, shimmer and radiation saturation.

There are four requirements for good Infra-red detector performance:

1. The infra-red cell must have a good view of the flame

2. The infra-red cell must be protected from the infra-red radiation of the hot refractory.

3. The infra-red cell temperature cannot exceed 125 degrees Fahrenheit.

4. Proper wiring procedures must be followed:

    a. maximum distance from detector to the programmer is 50 feet
    b. the protective flexible metal conduit that surrounds the wires must be grounded at the programmer
    c. Any junction boxes must be grounded
    d. The wiring must be BX, shielded cable, or twisted pair
    e. No other wiring can run in the conduit that has the leads from the infra-red detector
    f. Rigid conduit is recommended. If flexible metal conduit is used it must be securely fastened to prevent vibration. Vibration of the wiring at the correct frequency can cause a false positive reading to the programmer.

ULTRAVIOLET FLAME DETECTORS

The ultraviolet flame detector uses an anode and cathode encased in a special quartz glass gas filled tube. The reason that the ultraviolet tube is sealed in a special quartz glass tube is that regular glass would block the ultraviolet radiation. In the presence of a flame, the flame will ionize the gas in the tube, conduct electricity through the gas and allow an electric circuit to be completed. As the gas becomes ionized, it will glow with a reddish or blue glow. When the tube is not in the presence of a flame it will randomly glow. This is called "background count" and it is not strong enough to fool flame safeguard device into thinking that a flame is present.

Precautions to be taken when using UV detectors:

1. Since sparks emit ultraviolet radiation, special precautions must be made so that the detector does not give false positive readings. The detector must be sighted so that it observes only the flame of the pilot and not the spark igniter.

2. The ultraviolet flame detector must be sighted so that it observes the first 1/3 of the flame

3. Depending upon the model, the ultraviolet flame detector has an allowable temperature range that varies from 125 degrees Fahrenheit to 250 degrees Fahrenheit. While this is higher than the other detector types, cooling precautions may have to be taken.

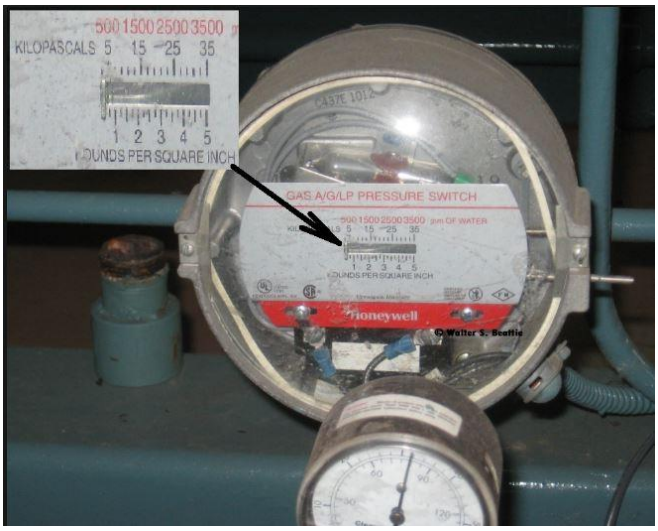
4. The ultraviolet flame detector must not "see" refractory hotter than 2500 degrees F. because above that temperature the refractory will give off ultraviolet radiation that can fool the detector.

FLAME SAFEGUARD CONTROLLER

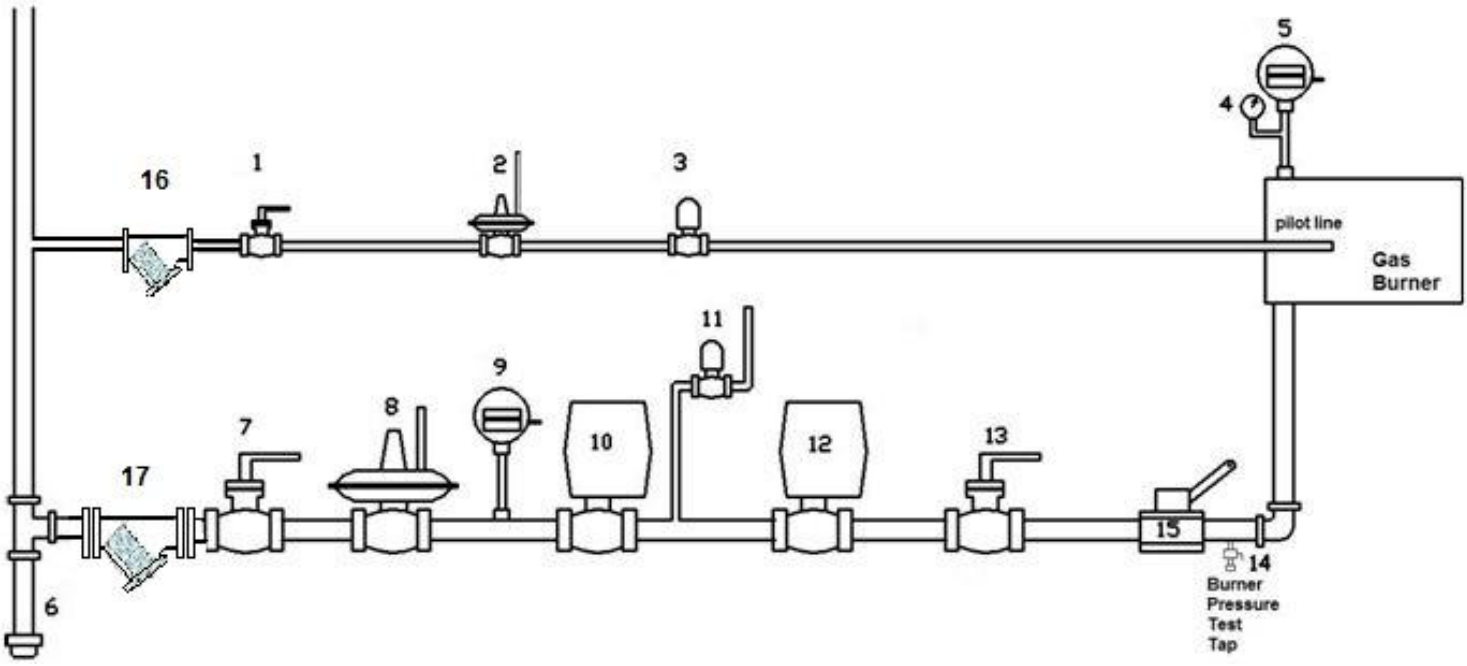
The flame safeguard controller starts the burner in the proper sequence and guards against unsafe conditions during start-up. It also is constantly checking the flame to ensure that no unsafe condition occurs in the furnace during operation. When the burner is turned off at the stop switch, it ensures an orderly shutdown with a postpurge to clear the furnace of any unburned gasses. The flame safeguard controller should also have self-diagnosing capabilities to ensure that the burner is shut down if the flame safeguard controller develops a problem with itself. Other safety devices are hooked to the flame safeguard controller to ensure that the burner will shut off if unsafe conditions occur. These devices include:

1. The low water cutout
2. High and low fuel pressure switches
3. Forced draft and induced draft fan interlocks
4. High or low oil temperature cutouts
5. Damper position lockout

Fan Interlock Switch



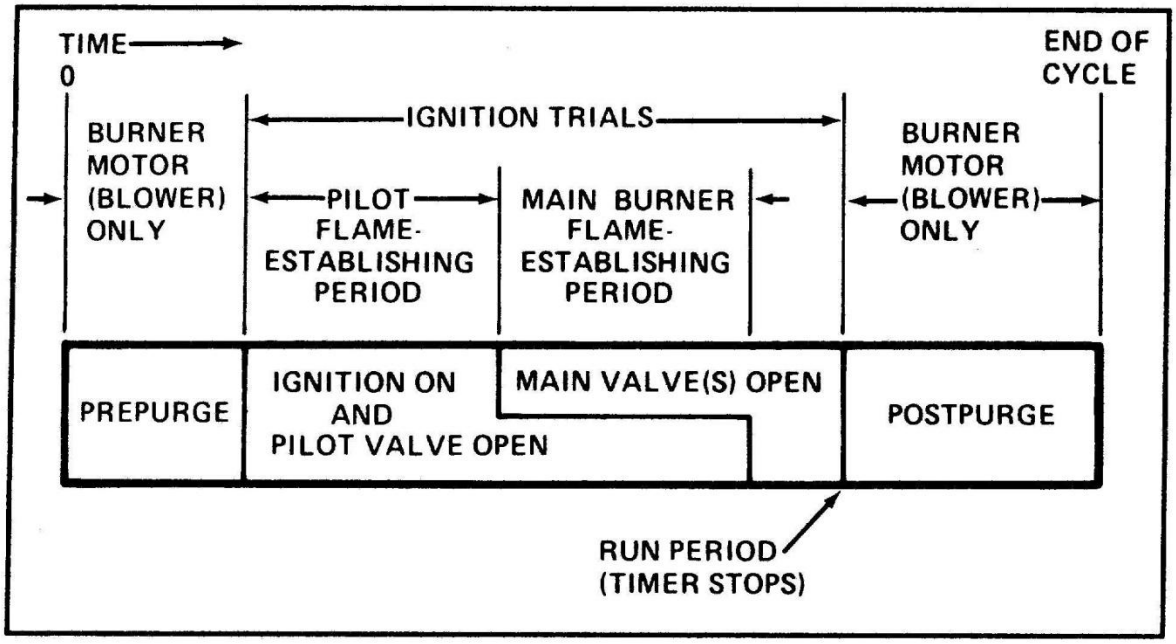
GAS TRAIN



Let's discuss a gas train and all the components that are needed for it to function safely. The main gas line is coming down at the left and ends at a sediment and scale trap at #6 which is nothing more than a tee with a long pipe nipple screwed into it so that dirt will fall to the bottom before entering the gas train itself. #16 and #17 are strainers to catch any debris before they get to components of the gas train. #1 is the pilot line manual shutoff valve. #2 is the pilot pressure regulator with a vent on top of the diaphragm in case the diaphragm should leak. #3 is a solenoid that will open when the combustion control calls for it to send gas to the igniter to start the pilot flame.

#7 is the main manual gas shutoff valve. #8 is the main pressure regulator with a vent line just like the pilot line. All the vent lines are piped above the roof. #9 is the low gas pressure cut-out with manual reset. #10, #11, and #12 are safety features that combined together are known as "double block and bleed." All that funny sounding term means is that there are two safety shutoff valves in series with a vent solenoid in between. When the boiler is off, both #10 and #12 are shut and #11 is open. Any gas that leaked past #10 will take the path of least resistance and go up the vent valve 11 before going into the boiler. When the pilot flame is proven, #10 and #12 will open and #11 will shut. #13 is another manual shutoff valve so you can isolate and service any parts between #7 and #13. #14 is a burner pressure test tap to attach a gauge to for pressure testing. #15 is the modulating valve, usually a butterfly valve, that will adjust the gas flow to the boiler load. The modulating valve will have linkage connecting it to a modulating motor and a fan damper that are not shown. #4 is a gas pressure gauge and #5 is a high gas pressure shutoff with a manual reset.

This is a good drawing to use if the License Examiner asks you to draw a Gas Train.



Now let's discuss the timer cycle when you flip the start switch on the burner and what timed sequence occurs. The programmer motor starts its cycle and the blower motor starts its prepuge cycle where it will open the dampers wide and blow 5 furnace volumes of air through the furnace to make sure there are no combustible gasses in the furnace before the burner starts. After the prepurge time ends (and it will vary depending upon the size of the blower and furnace), the damper will close down to its starting position. The modulating motor will put the gas modulating valve in a minimum open position. Valves #10 and #12 are shut so no gas will flow into the furnace. Solenoid #3 will open while a spark igniter inside the gas burner will start sparking until the pilot lights and the flame scanner is satisfied that the pilot has been established.
That is the Pilot Flame Establishing Period under the Ignition Trials. After the Pilot is established, main gas valves #10 and #12 will open and #11 will close. The gas will instantly ignite as it hits the pilot flame and The Main Burner Flame Establishing Period will start. Once the flame scanner is satisfied with the flame, the pilot solenoid will shut and the controller will allow the burner to respond to load changes as long as the run period lasts. The timer stops turning at this point. Once the run time has ended, either from a pressuretrol, safety shutdown, or the Operator turning the switch to off, the Postpurge will start. Valves #10 and #12 will shut and valve#11 will open. The fan damper will open wide and the blower will run air through the furnace to flush out any unburned gasses. The cycle timer will then go back to the start and wait for the next start signal.

In conclusion, modern flame safety controls have come a long way in insuring that the burners of modern boilers are safe to operate.

Chapter 17

PRACTICAL ELECTRICITY

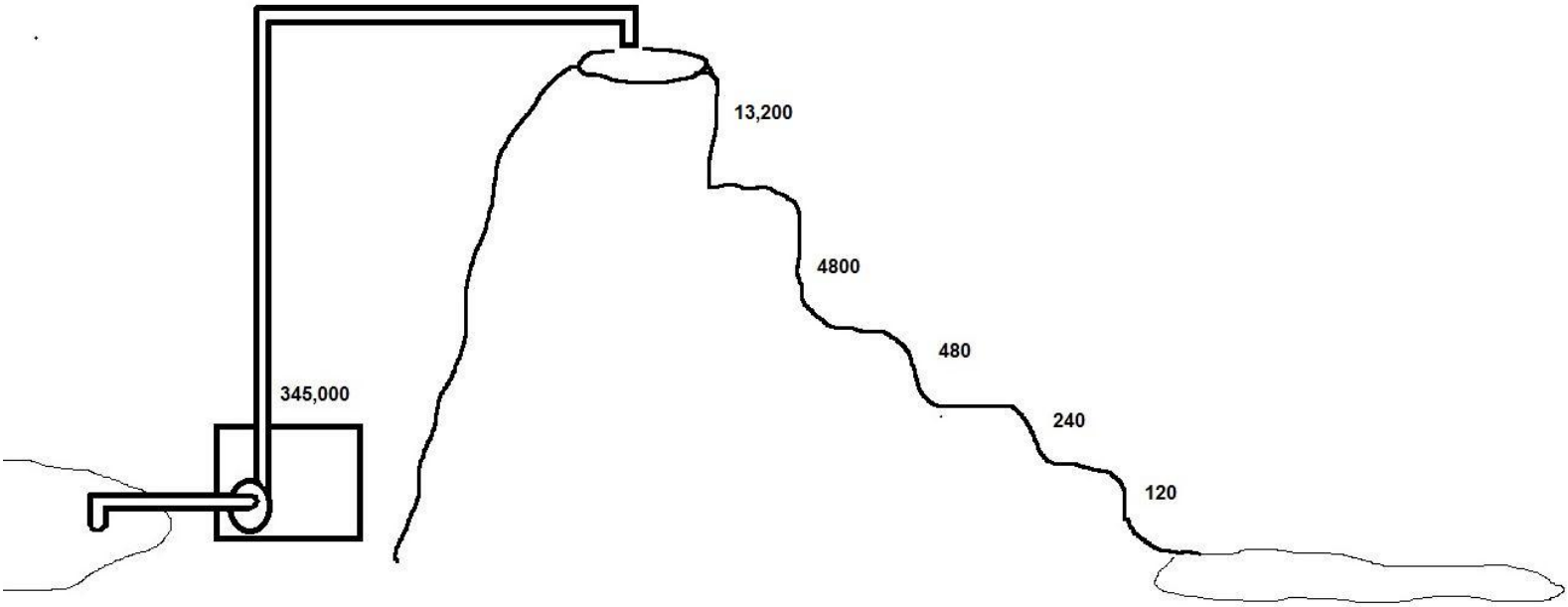
British Science Fiction author's Arthur C. Clarkes third law states that "Any sufficiently advanced technology is indistinguishable from magic." Electricity is magic. It is magic because no one has yet explained what it is. That's not to say you cannot read in a book that it is the flow of electrons down a wire, or atoms with electrons whirling about, but if you really think about it, no one really explains what it is satisfactorily. Electrons used to travel from positive to negative. Now they travel from negative to positive. Run water through a pipe for 50 years and the pipe will wear away from erosion. Run electrons through a wire for 50 years and the wire is the same size as it was when it was new.

The good thing about electricity is that it can be measured, changed in voltage, and run any number of gadgets and labor saving devices. We are interested in the practical aspects of electricity, and will leave the theory to others.

Michael Faraday, in 1831 discovered that you could create a continuous flow of electricity by moving a magnet through a coil of wire. This led Nicolai Tesla to invent Alternating Current generators that could create electricity and transformers that could step up the voltage so that electricity could be carried long distances.

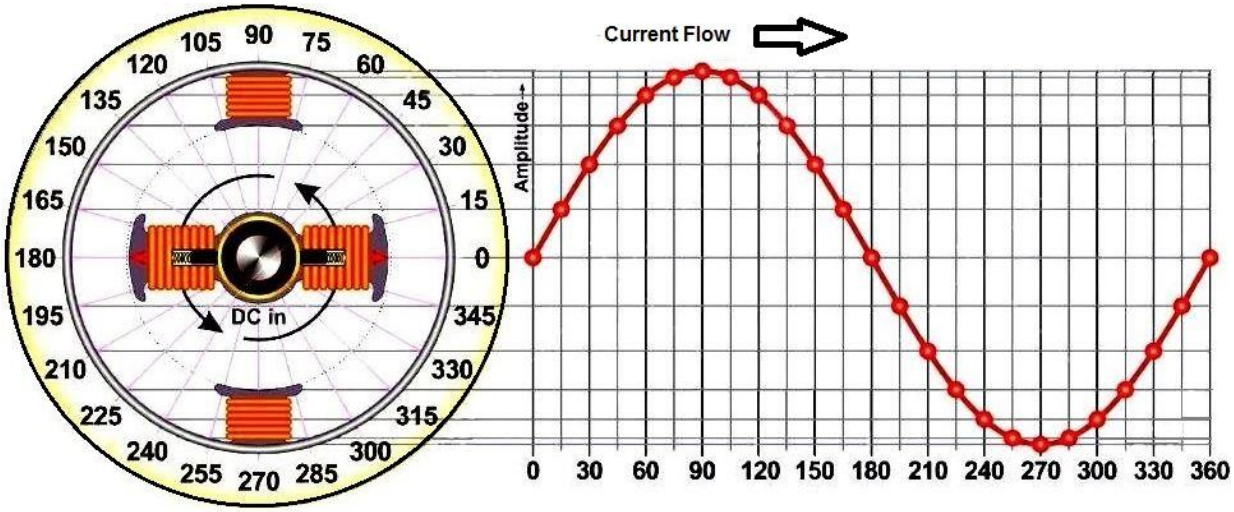
Electricity also creates magnetism. The generator at the powerplant is tapped at 3 different spots on the stator coil at 120 degrees of a 360 degree circle. This creates a 3 phase current and a rotating magnetic field. Travel 100 miles away from the Power Station and put a circular coil of wire inside a hollow cylinder. Then put an iron cylinder mounted on a rod with bearings at both ends and no wiring connection between the coil and the rotating part and you have a 3 phase motor. Pretty magical stuff.

Let's tell a story about water and then draw parallels to electricity. You have a pumping station at ground level next to a lake. You pump this water up high into the mountains with a pressure of 24,000 psi and a flow of 850 million gallons per minute. Once this water is pumped into a reservoir at the top of the mountains at great height, it can now come down at a pressure of 345 000 psi and 845 million gallons per minute. It lost some pump pressure due to the resistance of the pipes. On its way down the hill, it made several stops at other holding reservoirs where the pressure dropped to 13.200 psi, then 4800 psi, then 480 psi, then 240 psi, and finally 120 psi before it flows back to a lake at ground level at zero psi.

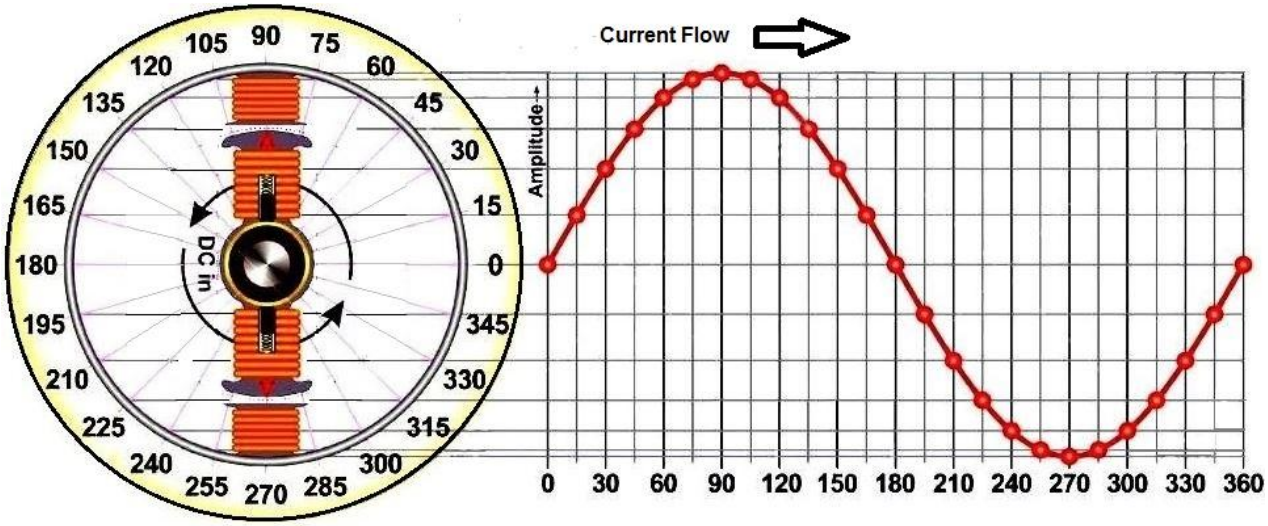


Now let's say we are at the Monroe power station of DTE. They generate electricity at 24,000 volts at 850 megawatts from one of their steam turbine generators. We step up the voltage with transformers outside the plant to 345,000 volts. As we move across the electrical service area, we step down the voltage to 13,200 volts, then to 4800 volts, then to 480 volts for use in factories, then down to 240 volts to feed your electric oven and finally to 120 volts for the lights and electrical outlets in your house. From there it flows at zero volts back to ground level.
Voltage is electrical pressure like water pressure in a pipe. Current in amps is the amount of electricity flowing or like the gallons per minute flowing through a pipe. Resistance is the opposition to flow or like the roughness inside the pipe.

Some books misstate that DC current goes in one direction and AC current alternates back and forth 60 times a second. Both currents come from a source of higher voltage and goes toward a load IN ONE DIRECTION. Your electric light bulb does not generate power that goes back to the Power Station. The confusion comes from the term "back and forth", making some people believe that electricity is going back and forth like a person pacing in a room. AC Electricity alternates UP and DOWN in power intensity as viewed from a ground level standpoint in one direction.

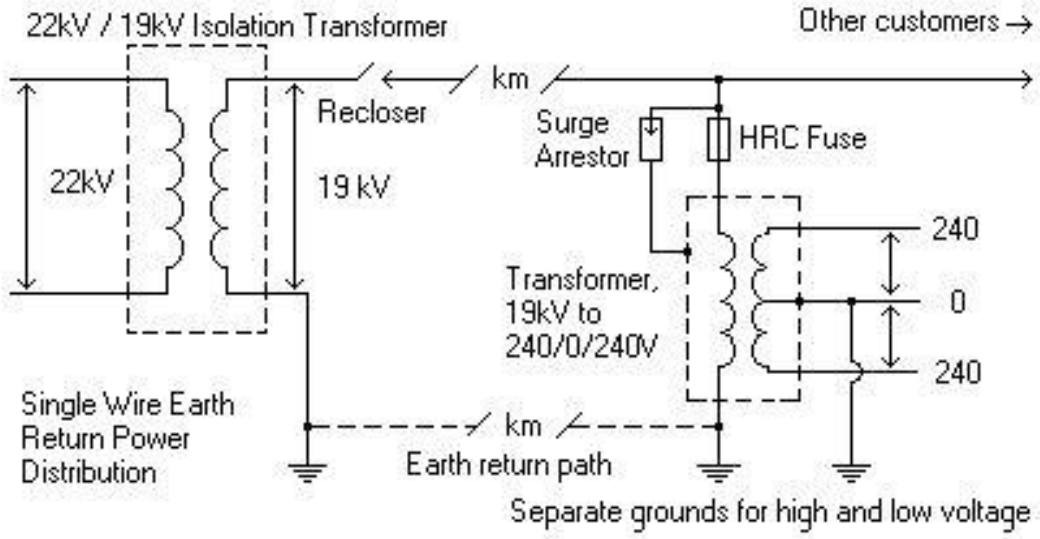


In the AC Generator picture above start at 0 and start going counter-clockwise around the circle. At the start, 90 degrees away from the top coil, there is zero electricity generated. As the rotor goes toward the top, it starts generating current until it generates the maximum at the top at its peak. This is called the positive direction.



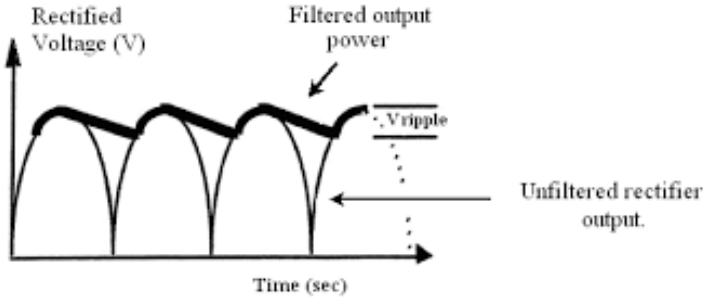
As the rotor continues around, at 180 degrees it is back at zero. The rotor then continues toward the 270 degree mark where it is at maximum in the negative direction. The rotor continues its rotation until it is back at 0 or 360, its starting point. Note that the current flow is in one direction, from the generator toward the load. Negative direction is misunderstood sometimes to mean "less than". The power generated in the negative direction is just as powerful as current generated in the positive direction. The creates the sine wave of AC power, 60 times a second.

You may have heard that you have to complete a circuit to get electricity to flow. This is partially correct. Pressure runs from high to low and electricity runs from high to low. You do not have large copper lines running back to the Power Station to complete the circuit. You run a copper rod into the ground in the plant or outside your house and after the electricity has done its work, the electricity ends up there. The Earth is the ultimate ground for AC power.
In rural parts of New Zealand, they use a Single Wire Earth Return system. There is just one wire that goes to each house. That wire goes to the hot side of lights and electrical receptacles. The neutral and ground meet at the circuit breaker panel and a ground rod is driven into the ground. A good earth connection is normally a 20 foot length of copper-clad steel driven vertically into the ground, and bonded to the transformer ground. A good ground resistance is 5–10 ohms. SWER systems are designed to limit the voltage in the earth to 20 volts per meter to avoid shocking people and animals that might be in the area.



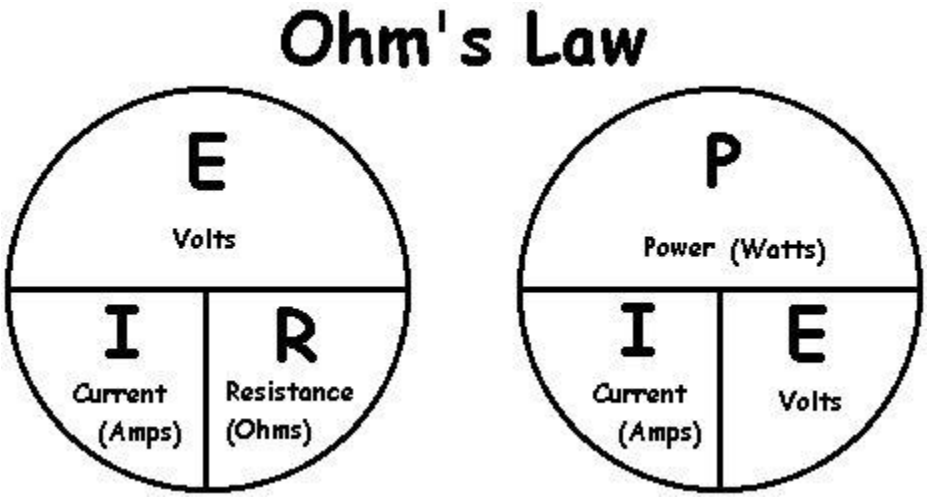
This drawing shows a Single Wire Earth Return schematic. The 22kV transformer at the far left has a 19kV secondary with one end of the transformer hooked to a rod driven into the ground. The single wire then runs overhead on a tall pole until it comes to a house where a wire is tapped off the overhead line to come to the house. After passing through a fuse, it goes through a transformer at the pole and then 3 wires come to the circuit breaker panel to provide 240 volts to the house. All of New Zealand uses 240 volts as compared to 120 volts in the United States. The Ground wire then goes directly to the outside rod or rods driven into the ground. The return path is considered to be through the earth itself.

A DC circuit from a battery is the straight line that you see in books. DC can be created from AC by using a rectifier. The DC from a rectifier is anything but a straight line. In a full wave bridge rectifier it "flips" the negative portion of the sine wave to the positive so it looks more like a bumpy road than a straight line.



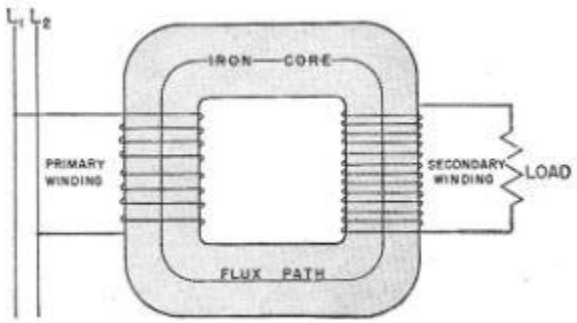
The "filtered" DC uses coils of wire to try to smooth out the bumps. The Flame Rectifier of a Flame Rod on a boiler does not even flip the negative portion of the sine wave. It just flattens it so that the sine wave can be recognized as being more toward DC than true AC.

The relationship between voltage, current, and resistance is best explained by learning Ohm's Law. Practice drawing these two circles:

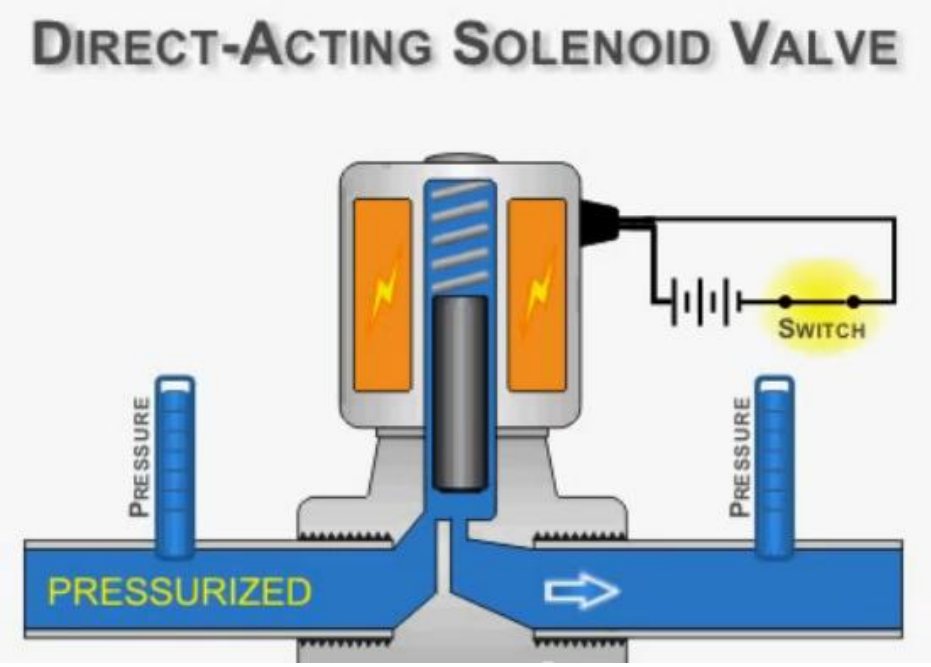


These are helpful aids to answer any questions about DC circuits that might be on an exam. Cover what answer you are looking for and the formula is right there. Need to know voltage? E= Current times Resistance in the first circle and E= Power in Watts divided by Current in the second circle. Example: What is the DC voltage of an electrical circuit with a current of 12 amps and a resistance of 10 ohms? 12 times 10 equals 120 volts

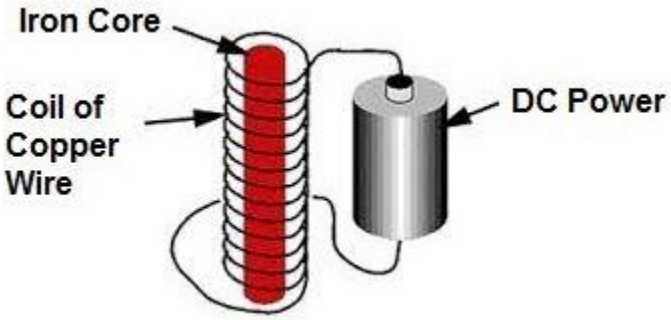
At the boiler room you may have alternating current at 4800 volts if you work in an industrial plant that has large air compressor motors. Transformers will lower the voltage to 480, 240, and 120 volts. If you work in an office building you may have lighting fixtures that operate at 277 volts. Winding copper wire in a coil has many useful properties. If you wrap the coil of wire around laminated steel and put another coil of wire on the other end of an open square of the laminated steel, you have created a transformer. You can step the voltage up or down in a direct ratio of the number of wires on one end compared to the other.



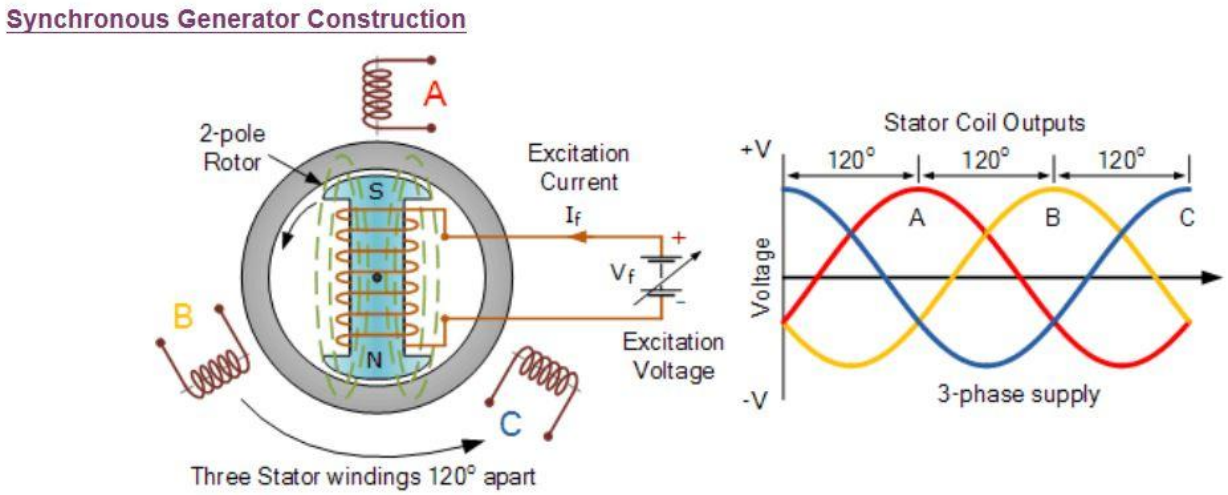
A solenoid is a coil of wire that has a spring loaded plunger that can be pulled up when the coil is energized to start or stop flow. Do not allow a solenoid coil to become energized while repairing the valve without a metal rod or screwdriver in the middle of the coil. A coil of wire without an iron rod in the middle will catch fire.



A small transformer also known as a ballast is found in fluorescent lighting fixtures to build up enough voltage to jump the gap of a 4 foot tube filled with a gas containing low pressure **mercury vapor** and **argon**, **xenon**, **neon**, or **krypton**. These bulbs are being phased out of the marketplace and replacements will be hard to find.



Winding copper wire around a metal rod will create an electromagnet.



A synchronous generator at a Electrical Generating Station in the United States has a 2 pole rotor with Direct Current energizing the rotor to create a powerful electromagnet, just like a bar magnet. Spin that magnet at 3600 revolutions per minute inside a coil of wire that is tapped every 120 degrees of a circle and you have 3 phase alternating current. Most medium to large motors in your boiler room will be 3 phase because they are smaller and cheaper to buy than other types. 3 phase motors have high starting torque. 3 phase motors can have their rotation reversed by switching any two of the three leads, either at the motor or the motor control center.

Small motors in your boiler room will be single phase. They may have capacitors to help get them started.

All these coils of wire are useful but they have a drawback. These coils of wire impede the flow of electricity through them. This is called impedance which is another opposition to flow besides the resistance of the wire. Power Factor is the relationship of the electricity that does useful work to the electricity that is wasted by the impedance of coils of wires in the boiler room. If you have a low power factor, the Utility Company will charge you more on your electric bill. This is known as a lagging power factor.

Capacitor Bank

A capacitor is a container that has two thin sheets of metal with a non-conducting paper or other non-conductor called a dielectric in between them. Roll it up into a cylinder, stuff it into the container with a wire connected to each metal strip and you have a capacitor. They store electrical charges and have a leading power factor. You will have to install large capacitors if your power factor is too low, in order to correct the power factor to the Utilities satisfaction.

Air Cooled Transformer. Note the Fans on the bottom

Oil Cooled Transformer. Note the Radiator Fins on the back

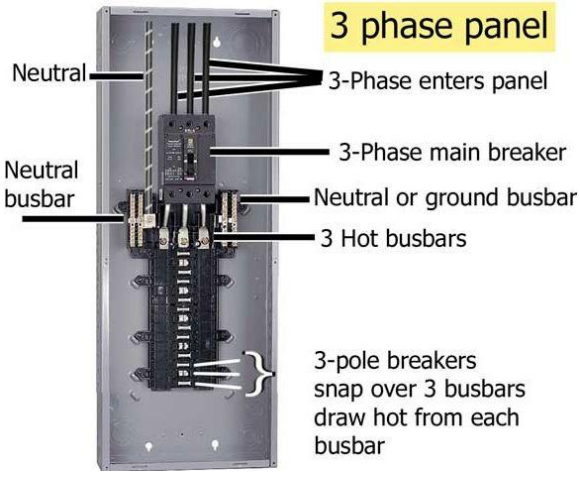
Most boiler rooms will have a "substation" room where transformers and switchgear is located. The transformers can be air cooled with multiple fans or oil cooled with "radiators". The fans on the air cooled transformers do not last a long time and should be checked on your rounds if a light on the panel shows that they should be on. The fans are changed by an electrician qualified to work with high voltage, not the Boiler Operator. You merely notify him.

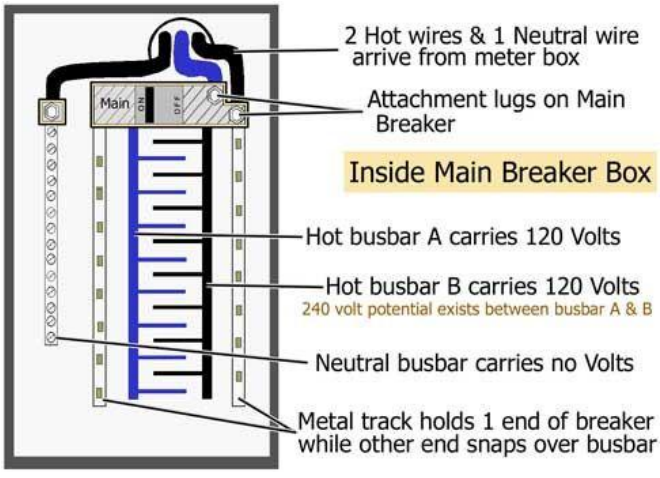
Before

After

The switchgear is fed from the transformer and houses large circuit breakers attached to busbars of copper or aluminum to distribute the electricity to smaller breaker panels and motor control centers.

It takes specialized training to open and close these breakers and it is beyond this PDF to provide those details. These pictures are merely to give you some background in the items you may find in your boiler room. The load centers or breaker panels are fed from here.




2 Hot wires & 1 Neutral wire arrive from meter box
Main
ON
OFF
Attachment lugs on Main Breaker
Inside Main Breaker Box
Hot busbar A carries 120 Volts
Hot busbar B carries 120 Volts
240 volt potential exists between busbar A & B
Neutral busbar carries no Volts
Metal track holds 1 end of breaker while other end snaps over busbar

There are 3 phase and single phase breaker panels and motor control centers fed from those large switchgear circuit breakers. You may have to reset or lock out these breakers as a Boiler Operator.

Circuit Tracing Kit

The breaker panel box (also known as a load center) should have a panel sheet that lists what lighting and power plugs and pieces of equipment are fed from each breaker. These need to be updated as changes are made. Electricians in boiler rooms seldom do this job accurately and it falls upon the Boiler Operator to make sure his equipment is properly identified on the panel. They have circuit tracers that can be invaluable in tracing what breaker feeds what piece of equipment. You cannot just start shutting off breakers in a boiler room like you might do at home. An advanced circuit tracer can:

a. Trace live wires buried or hidden behind walls.
b. Trace unenergized and open (broken) wires
c. Perform tests without having to interrupt power
d. Locate breakers, neutral and ground lines
e. Locate and trace wires in walls, floors, conduit, computer cables, etc.
f. Pinpoint shorts, ground faults and broken wires

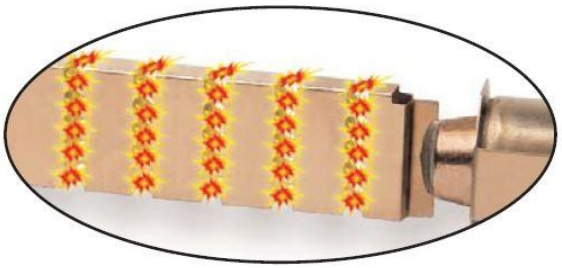
When you are going to work on a piece of equipment that is fed from a breaker panel, you need to Lock Out and Tag Out that breaker so no one can come by and energize that piece of equipment and hurt or kill you. Only you have the key to that padlock.

A circuit tracing pen can be used to test whether a circuit is "live" or not. Do not trust your life with them but they can be handy to have.

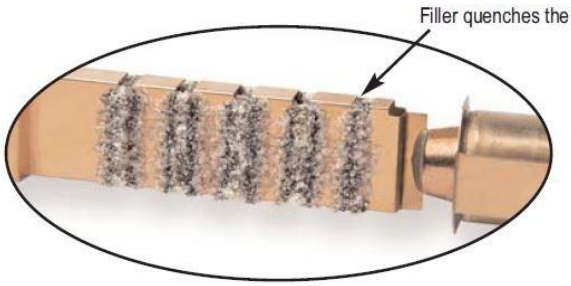
FUSES

Fuses are used to protect equipment and wiring from short circuits and overloads.
A short circuit is an electrical circuit that allows current to travel along an unintended path, often where essentially no (or a very low) electrical impedance is encountered. Tremendous amperage is created and a very real danger of instantaneous fire is probable if a fuse is not there to stop the flow of electricity.

There are all kinds of fuses for different voltages and different amperage ratings. The Electrical Engineer who designed your boiler room specified specific fuses to be used. Those exact replacements should be on hand. There are time delay fuses to allow motors to start without opening the fuse. Electric motors have a large inrush current for a few seconds until the motor gets up to speed. Time delay fuses permit the motor to start. If it continues to draw too much current, the fuse will open. Some fuses have rejection clips so that larger amperage fuses cannot be substituted. The obsolete glass screw in fuses would allow a 30 amp fuse in a 15 amp circuit. Very dangerous and a definite fire hazard.



Short circuit operation: Modern fuses are designed with minimum metal in the restricted portions which greatly enhance their ability to have excellent current-limiting characteristics – minimizing the short circuit let-through current. A short-circuit current causes the restricted portions of the short circuit element to vaporize and arcing commences. The arcs burn back the element at the points of the arcing. Longer arcs result, which assist in reducing the current. Also, the special arc quenching filler material contributes to extinguishing the arcing current. Modern fuses have many restricted portions, which results in many small arclets – all working together to force the current to zero.



Short circuit operation: The special small granular, arc-quenching material plays an important part in the interruption process. The filler assists in quenching the arcs; the filler material absorbs the thermal energy of the arcs, fuses together and creates an insulating barrier. This process helps in forcing the current to zero. Modern current-limiting fuses, under short circuit conditions, can force the current to zero and complete the interruption within a few thousandths of a second.

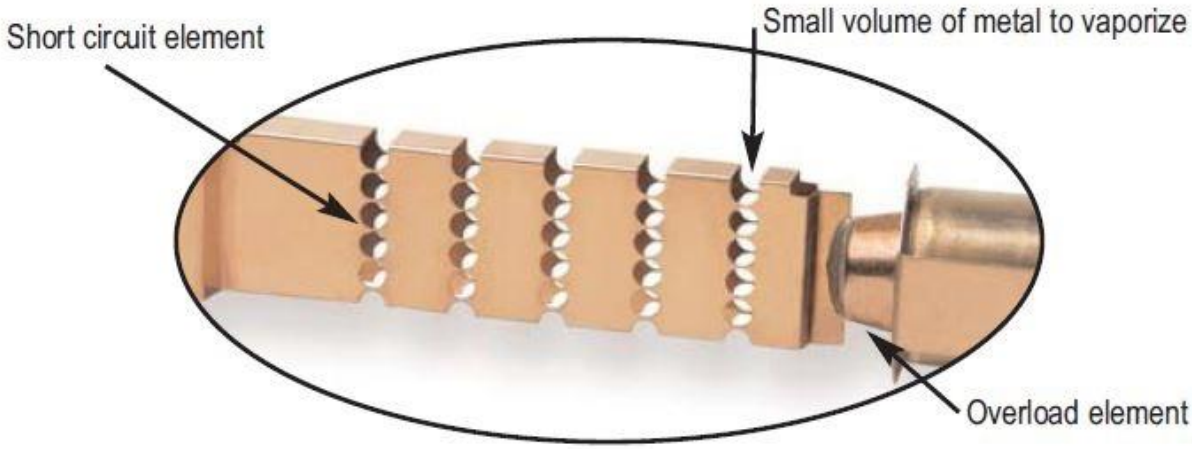
Figure 1. Cutaway view of typical single-element fuse.

Figure 2. Under sustained overload, a section of the link melts and an arc is established.

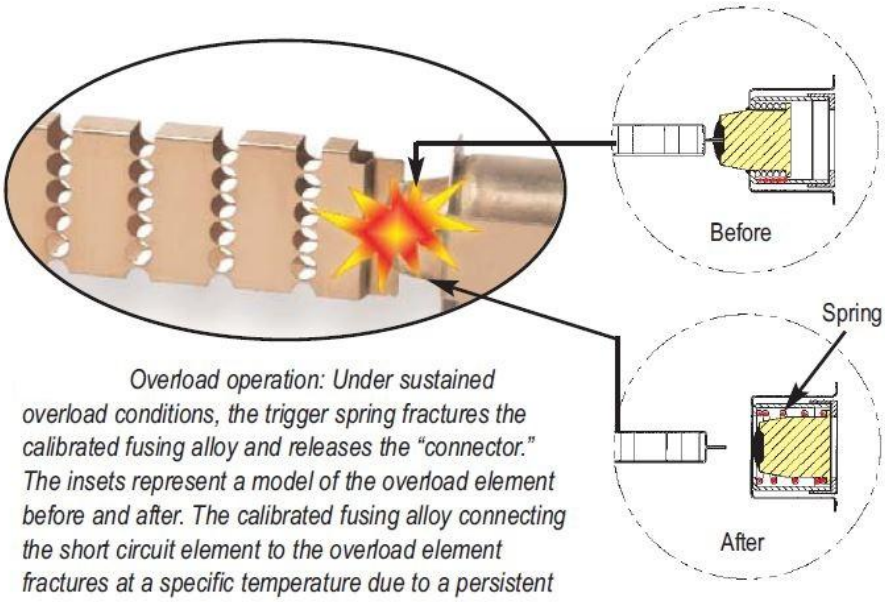
Figure 3. The "open" single-element fuse after opening a circuit overload.

Figure 4. When subjected to a short-circuit current, several sections of the fuse link melt almost instantly.

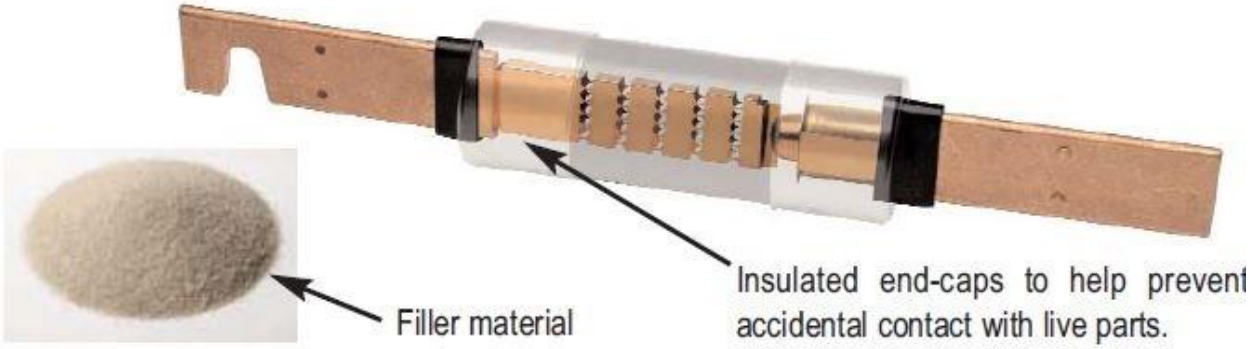
Figure 5. The "open" single-element fuse after opening a shorted circuit.



The true dual-element fuse has distinct and separate overload element and short circuit element.



Overload operation: Under sustained overload conditions, the trigger spring fractures the calibrated fusing alloy and releases the "connector." The insets represent a model of the overload element before and after. The calibrated fusing alloy connecting the short circuit element to the overload element fractures at a specific temperature due to a persistent overload current. The coiled spring pushes the connector from the short circuit element and the circuit is interrupted.



This is the LPS-RK100SP, a 100A, 600V Low-Peak, Class RK1, dual-element fuse that has excellent time-delay, excellent current-limitation and a 300,000A interrupting rating. Artistic liberty is taken to illustrate the internal portion of this fuse. The real fuse has a non-transparent tube and special small granular, arc-quenching material completely filling the internal space.

The inside of a small time delay fuse with the cardboard cover and sand removed. Fast acting fuse is on the right

Branch Circuit Fuses (All Voltage and Interrupting Ratings are AC)

Class R Dual-Element, Time-Delay				Class G	Class CC Fast-Acting, Time-Delay		
LPN-RK_SP 1/10-30A 250V 300K AIR	**FRN-R** 1/10-30A 250V 200K AIR	**FRS-R** 1/10-30A 600V 200K AIR	**LPS-RK_SP** 1/10-30A 600V 300K AIR	**SC** 1/2-20A 600V§ 25-30A 480V§ 100K AIR	**KTK-R** 1/10-30A 600V 200K AIR	**FNQ-R** 1/4-30A 600V 200K AIR	**LP-CC** 1/2-30A 600V 200K AIR

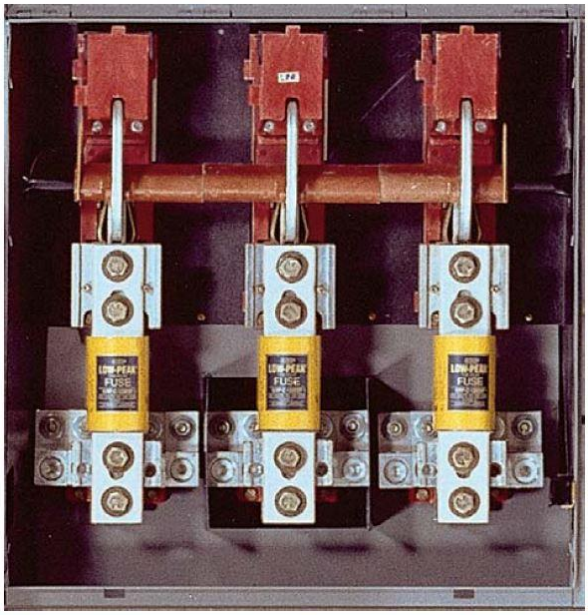
Different types of power fuses

Supplementary Fuses (13/32" x 1 1/2") (All Voltage and Interrupting Ratings are AC)

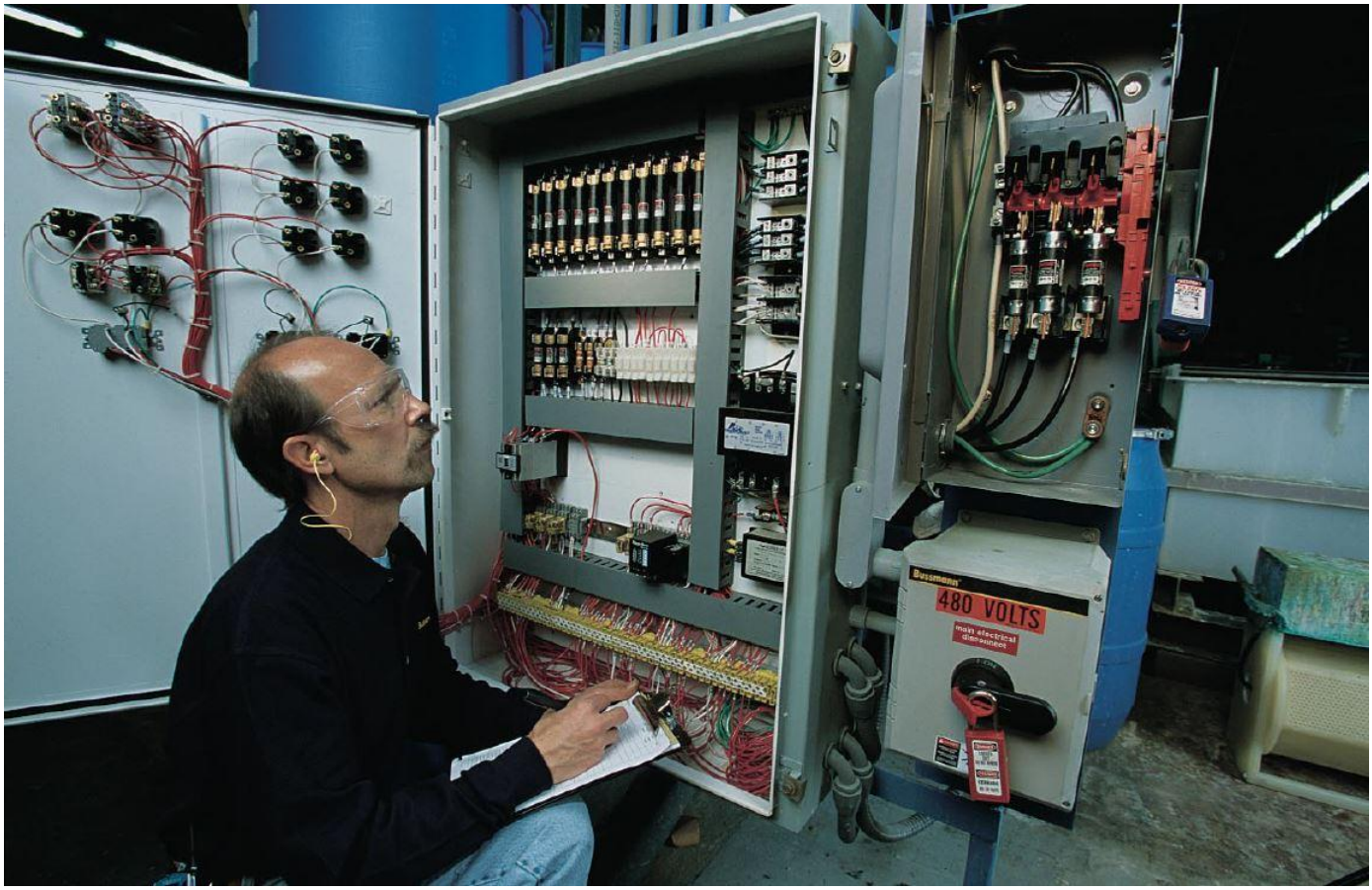
Dual-Element, Time-Delay		Time-Delay		Non-Time-Delay				
FNA 1/10-8/10A 250V† 1-15A 125V* 20-30A 32V**	**FNM** 1/10-10A 250V† 12-15A 125V* 20-30A 32V**	**FNQ** 1/10-30A 500V 10K AIR (FNQ 1/10 - 3 3/10 Dual-Element)	**FNW** 12-30A 250V*	**BAF** 1/2-15A 250V† 20-30A 125V*	**BAN** 2/10-30A 250V††	**KTK** 1/10-30A 600V 100K AIR	**MIC** 1-15A 250V† 20-30A 32V**	**MIN** 1-15A 250V† 20-30A 32V**

Smaller fuses normally used on control circuits

The fuse clip on the right has excellent tension that provides a good mechanical and electrical interface (low resistance) between the fuse and clip. The clip on the left experienced excessive thermal conditions due to an improper conductor termination or undersized conductor. As a result, the clip lost its tension. Consequently, the mechanical and electrical interface between the fuse and clip was not adequate which further accelerated the unfavorable thermal condition.



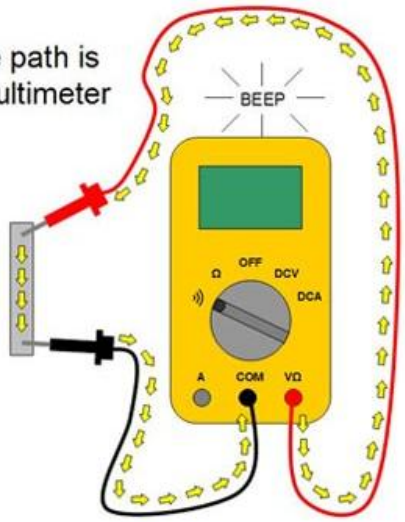
Bolted in Fuses



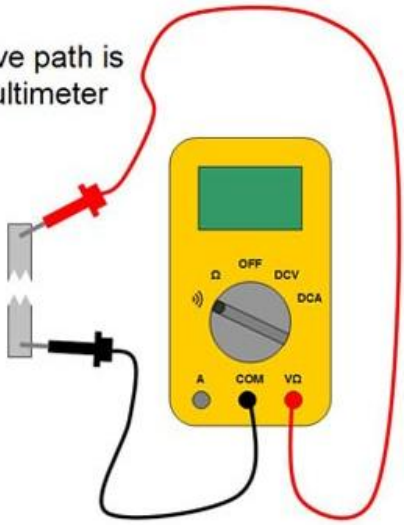
Notice that the technician has opened the switch at both panels on the right and put lockout locks on the switch handles so they cannot be reclosed. Note the large number of fuses within the panel. A fiber fuse puller would be used to pull the suspect fuse and check for continuity. The cause of the fuse failure should be determined before the fuse is replaced.

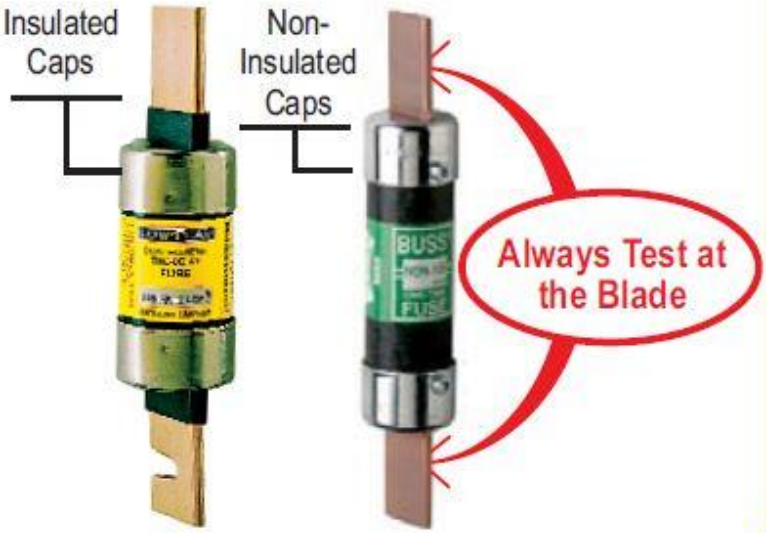
FUSE TESTING

If a conductive path is formed, the multimeter will beep.



If the conductive path is broken, the multimeter will not beep.

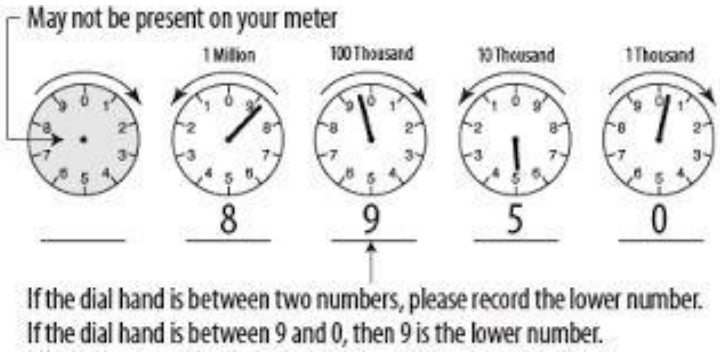




A continuity test across any knife-blade fuse should be taken *ONLY* along the fuse blades. Do *NOT* test a knife-blade fuse with meter probes to the fuse caps.

Fiber non-conductive fuse pullers

HOW TO READ A UTILITY METER


May not be present on your meter
1 Million
100 Thousand
10 Thousand
1 Thousand
8
9
5
0
If the dial hand is between two numbers, please record the lower number.
If the dial hand is between 9 and 0, then 9 is the lower number.

You read an analog meter from right to left, opposite the way you read this text. For the Kilowatt Hour (KWH) meter on the upper left, the reading would be 60169. For the Kilovar hour (KVARH) meter on the right the reading would be 19151. Note that dials as read from the right are clockwise, counterclockwise, clockwise, counterclockwise, clockwise. You write it down with the most right digit first, to see if it is before or after the zero, and then work to the left. A little confusing at first, but it just takes practice.

One of your jobs as a Boiler Operator may be to take the utility meter readings and log them in a log book or on a computer spreadsheet. You take the readings at midnight. There are usually two meters, a kilowatt hour or KWH meter and a Kilovolt Amphour Reactive meter or KVAR.
By taking these two readings, you can figure out you power factor for the day by the formula PF = kWH / Square root of (kWH^2 + $kVARH^2$) or Power Factor equals the square root of the (Kilowatt Hour Meter Reading times itself) plus the (Kilovar Hour reading times itself) added together.

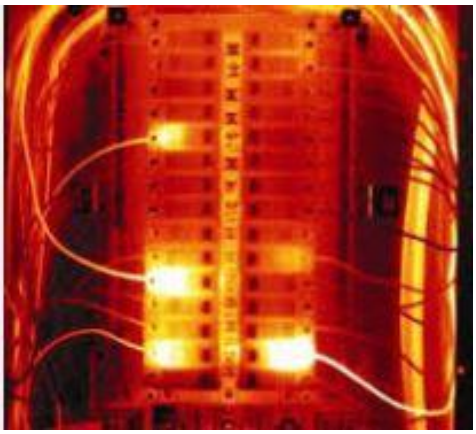
With a calculator it is not too difficult, with a spreadsheet formula it is easier still.

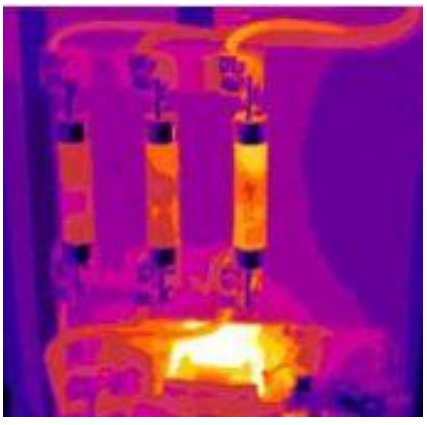
GE kV2c meter with KWH, KVAR, demand and power factor built in

They now make meters that will do all the math within the meter itself.

Utility Bills have a demand charge that is based upon the instantaneous maximum amount of electricity the plant used at that second. The Utility argues that it had to build substations and feeder cables large enough to handle that instantaneous demand and charges accordingly. Sometimes there is a window of time during the night to early morning they do not include in the demand calculation, say 8:00 pm to 6:00 am, although it varies from utility to utility. To avoid setting a new maximum, start large machinery before 6:00 am in this case, or spread out the starting of large equipment in 16 minute intervals to avoid large spikes in demand. There is usually a 15 minute window for demand checks. Check with your utility to see how demand charges are calculated for your plant.

All the machinery in the Boiler Room vibrates and it loosens screws and wiring connections. Whenever a boilers electrical panel is locked out and tagged out, go over all the screws in the panel and tighten them. Hiring a Thermal Imaging company to check all major wiring connections in the substation and breaker panels once a year is always a good idea.





Name	Service Address	Account Number
Acme Enterprises Attn: Accounting Dept	123 Main St Hanover IN 47243	0000-1234-05-6

11 Electric

Meter -	012345678
Multipliers -	40
kWh Usage -	56,760
Demand Read -	03.00
Actual kW -	120.00
Billed Kvar -	41.60
Power Factor -	94.4%

Jun 28 - Jul 27
29 Days

12 Duke Energy
Rate HSN0 - High Load Factor Sec Srv

Connection Charge		$ 15.00		
Demand Charge				
120.00 kW	@	$ 14.06000000	1,687.20	
Energy Charge				
56,760 kWh	@	$ 0.01583000	955.27	
KVAR Charge				
41.60 Kvar	@	$ 0.24000000	9.98	
Rider 60 - Fuel Adjustment				
56,760 kWh	@	$ 0.01420700	806.39	
Rider 61 - Coal Gasification Adj				
120.00 kW	@	$ 1.91436100	299.72	
Rider 62 - Pollution Control Adj				
120.00 kW	@	$ 2.04057600	244.87	
Rider 63 - Emission Allowance				
56,760 kWh	@	$ 0.00032300	18.33	
Rider 66 - DSM Ongoing				
56,760 kWh	@	$ 0.00021600	12.26	
Rider 67 - Cinergy Merger Credit				
56,760 kWh	@	$ 0.00029700cr	16.86cr	
Rider 68 - Midwest Ind Sys Oper Adj				
56,760 kWh	@	$ 0.00072500	41.15	
Rider 70 - Reliability Adjustment				
56,760 kWh	@	$ 0.00035700	20.26	
Rider 71 - Clean Coal Adjustment				
120.00 kW	@	$ 2.08452600	250.14	4,273.71

Total Current Electric Charges	**$ 4,273.71** 13

Let's look at a sample utility bill from Duke Energy. The actual energy charge is $955.27 for 56,760 Kilowatt Hours at about 1.6 cents (0.0158) a kilowatt hour which is a very cheap rate. The average homeowner might pay 7 cents a kilowatt hour. Look at the demand charge. It is $1687.20 which is almost double the amount paid for the electricity used.

All the riders are things the Public Service Commission allows the Utility to pass on to the consumer. The Coal Gasification Charge, Clean Coal adjustment, and Pollution Control adjustment does not mean that this customer uses coal. The customer could use natural gas but the Utility uses coal and is charging you for it.

Note that the power factor is 94.4% for this customer, which is good and there is no low power factor penalty on this bill. One way you can show your worth to your employer is by not setting a new demand peak on the utility bill.

ELECTRICAL SAFETY

Electricity is very dangerous. The higher the voltage, the greater the danger. As a Boiler Operator, you must follow all safety precautions to keep yourself from injury and death.

Arc Flash from getting too close to a high voltage panel and having the electricity jump out of the panel and make a deadly circuit through you to the ground.

The smallest electrical power circuit in a boiler room is 20 amps. A milliampere is 1/1000th of one amp. A shock of 50 to 150 milliamperes would lead to extreme pain, respiratory arrest, and severe muscular contractions. Death is possible.

Electrical burns are among the most serious burns and require immediate medical attention. They occur when electric current flows through tissues or bone, generating heat that causes tissue damage. A victim may suffer internal hemorrhages and destruction of tissues, nerves, and muscles that aren't readily visible. Kidney damage also can occur.

Application of high electrical field strength may cause thermal or electrochemical damage to internal tissues. Damage may include the destruction or dissolution of red blood cells, with subsequent release of hemoglobin, protein coagulation (cooking of cells), coagulation necrosis (cell death) of muscle and other tissues, blood clots, dehydration, and muscle and severing of the muscle or tendon from the bone.

High electrical field strength injuries may result in massive edema, which, as veins coagulate and muscles swell, results in compartment syndromes. Massive edema may also cause shock which is an emergency condition in which severe blood and fluid loss make the heart unable to pump enough blood to the body. Electricity will always be dangerous and one split second lapse in caution is all it takes for a lifetime of pain.

According to the Electronic Library of Construction Occupational Safety and Health (eLCOSH), exposure to electricity is still a major cause of death among construction workers. Among electricians, the most serious concern is working with or near live wires without enlisting the proper safety procedures. Electrocutions kill an average of 143 construction workers each year. Data from 1992 through 2003 indicates electrical workers suffered the highest number of electrocutions per year (586 or 34 percent of the total deaths caused by electrocution), followed by site laborers, carpenters, supervisors of nonelectrical workers and roofers.

More than half the electrocutions of electrical workers were caused by direct or indirect contact with live electrical equipment and wiring, including lighting fixtures, circuit breakers, control panels, junction boxes and transformers. In other words, those deaths could have been prevented had proper lockout/tagout and de-energizing procedures been followed.

The Occupational Safety and Health Administration (OSHA), Washington, D.C., estimates there are approximately 350 electrical-related fatalities a year, which roughly equals one fatality per day. In addition, statistics from the National Institute for Occupational Safety and Health (NIOSH), Atlanta, show electrocution is the third- leading cause of death at work among 16 and 17-year-old workers, accounting for 12 percent of all workplace deaths.

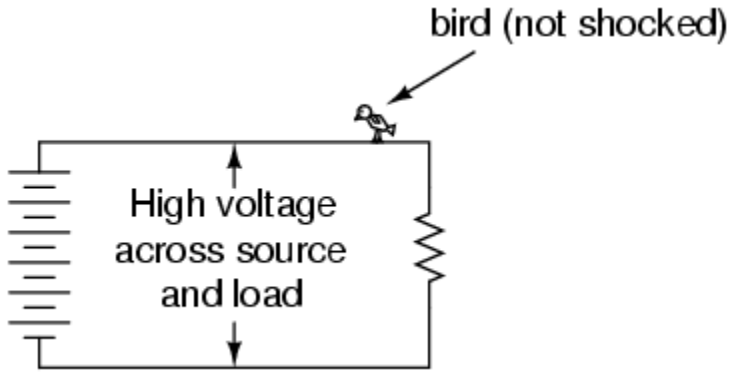
In addition, The Bureau of Labor Statistics (BLS) data indicates 2,726 nonfatal electrical shocks involved days away from work a year, between 1992 and 2001, in private industry.

"There are more than 30,000 nonfatal electrical shock accidents that occur each year, with a lot of incidents going unreported," said Chris Marquardt, safety director. According to OSHA, the occurrence of the most common injuries is increasing as the scope of work performed by the typical electrical contractor and the age of the work force increases

Guarding involves locating or enclosing electric equipment to make sure people don't accidentally come into contact with its live parts. Effective guarding requires equipment with exposed parts operating at **50 volts** or more to be placed where it is accessible only to authorized people qualified to work with it. Recommended locations are a room, vault, or similar enclosure; a balcony, gallery, or elevated platform; or a site elevated 8 feet or more above the floor. Sturdy, permanent screens also can serve as effective guards.

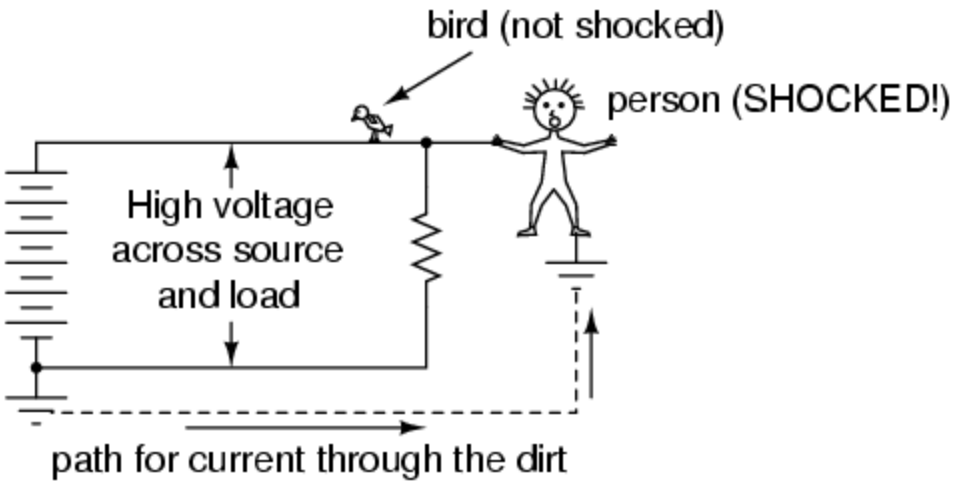
Conspicuous signs must be posted at the entrances to electrical rooms and similarly guarded locations to alert people to the electrical hazard and to forbid entry to unauthorized people. Signs may contain the word "Danger," "Warning," or "Caution," and beneath that, appropriate concise wording that alerts people to the hazard or gives an instruction, such as "Danger/High Voltage/Keep Out."

Without two contact points on the body for current to enter and exit, respectively, there is no hazard of shock. This is why birds can safely rest on high-voltage power lines without getting shocked: they make contact with the circuit at only one point.



In order for electrons to flow through a conductor, there must be a voltage present to motivate them. Voltage, as you should recall, is *always relative between two points*. There is no such thing as voltage "on" or "at" a single point in the circuit, and so the bird contacting a single point in the above circuit has no voltage applied across its body to establish a current through it. Yes, even though they rest on *two* feet, both feet are touching the same wire, making them *electrically common*. Electrically speaking, both of the bird's feet touch the same point; hence there is no voltage between them to motivate current through the bird's body.

This might lend one to believe that it's impossible to be shocked by electricity by only touching a single wire. Like the birds, if we're sure to touch only one wire at a time, we'll be safe, right? Unfortunately, this is not correct. Unlike birds, people are usually standing on the ground when they contact a "live" wire. Many times, one side of a power system will be intentionally connected to earth ground, and so the person touching a single wire is actually making contact between two points in the circuit (the wire and earth ground):

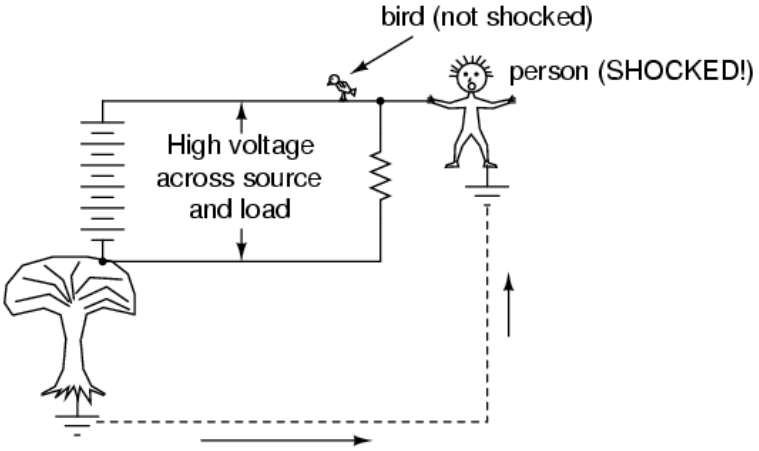


The ground symbol is that set of three horizontal bars of decreasing width located at the lower-left of the circuit shown, and also at the foot of the person being shocked. In real life the power system ground consists of some kind of metallic conductor buried deep in the ground for making maximum contact with the earth. That conductor is electrically connected to an appropriate connection point on the circuit with thick wire. The victim's ground connection is through their feet, which are touching the earth.

A few questions usually arise at this point in your mind:
1. If the presence of a ground point in the circuit provides an easy point of contact for someone to get shocked, why have it in the circuit at all? Wouldn't a ground-less circuit be safer?

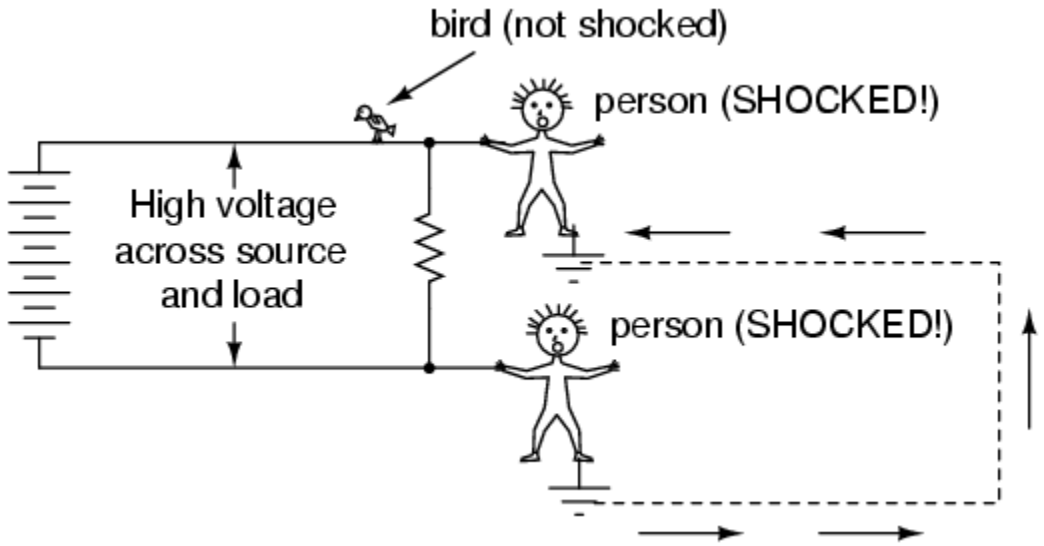
2. The person getting shocked probably isn't bare-footed. If rubber and fabric are insulating materials, then why aren't their shoes protecting them by preventing a circuit from forming?

3. How good of a conductor can *dirt* be? If you can get shocked by current through the earth, why not use the earth as a conductor in our power circuits?



accidental ground path through tree (touching wire) completes the circuit for shock current through the victim.

Such an accidental connection between a power system conductor and the earth (ground) is called a *ground fault*. Ground faults may be caused by many things, including dirt buildup on power line insulators (creating a dirty-water path for current from the conductor to the pole, and to the ground, when it rains), ground water infiltration in buried power line conductors, and birds landing on power lines, bridging the line to the pole with their wings. Given the many causes of ground faults, they tend to be unpredictable.



With each person standing on the ground, contacting different points in the circuit, a path for shock current is made through one person, through the earth, and through the other person. Even though each person thinks they're safe in only touching a single point in the circuit, their combined actions create a deadly scenario. In effect, one person acts as the ground fault which makes it unsafe for the other person. This is exactly why ungrounded power systems are dangerous: the voltage between any point in the circuit and ground (earth) is unpredictable, because a ground fault could appear at any point in the circuit at any time. The only character guaranteed to be safe in these scenarios is the bird, who has no connection to earth ground at all. By firmly connecting a designated point in the circuit to earth ground ("grounding" the circuit), at least safety can be assured at that one point. This is more assurance of safety than having no ground connection at all.

In answer to the second question, rubber-soled shoes *do* indeed provide some electrical insulation to help protect someone from conducting shock current through their feet. However, most common shoe designs are not intended to be electrically "safe," their soles being too thin and not of the right substance. Also, any moisture, dirt, or conductive salts from body sweat on the surface of or permeated through the soles of shoes will compromise what little insulating value the shoe had to begin with. There are shoes specifically made for dangerous electrical work, as well as thick rubber mats made to stand on while working on live circuits, but these special pieces of gear must be in absolutely clean, dry condition in order to be effective. Suffice it to say, normal footwear is not enough to guarantee protection against electric shock from a power system.

Hand or foot contact, insulated with rubber: 20 MΩ typical.

- Foot contact through leather shoe sole (dry): 100 kΩ to 500 kΩ
- Foot contact through leather shoe sole (wet): 5 kΩ to 20 kΩ

As you can see, not only is rubber a far better insulating material than leather, but the presence of water in a porous substance such as leather *greatly* reduces electrical resistance.

In answer to the third question, dirt is not a very good conductor (at least not when it's dry!). It is too poor of a conductor to support continuous current for powering a load. However, as we will see in the next section, it takes very little current to injure or kill a human being, so even the poor conductivity of dirt is enough to provide a path for deadly current when there is sufficient voltage available, as there usually is in power systems.

Some ground surfaces are better insulators than others. Asphalt, for instance, being oil-based, has a much greater resistance than most forms of dirt or rock. Concrete, on the other hand, tends to have fairly low resistance due to its intrinsic water and electrolyte (conductive chemical) content.

- **REVIEW:**
- Electric shock can only occur when contact is made between two points of a circuit; when voltage is applied across a victim's body.
- Power circuits usually have a designated point that is "grounded:" firmly connected to metal rods or plates buried in the dirt to ensure that one side of the circuit is always at ground potential (zero voltage between that point and earth ground).
- A *ground fault* is an accidental connection between a circuit conductor and the earth (ground).
- Special, insulated shoes and mats are made to protect persons from shock via ground conduction, but even these pieces of gear must be in clean, dry condition to be effective. Normal footwear is not good enough to provide protection from shock by insulating its wearer from the earth.
- Though dirt is a poor conductor, it can conduct enough current to injure or kill a human being.

Chapter 18

WATER TREATMENT

Boilers need fresh, clean water to operate correctly. Rainwater is fresh, clean water. Unfortunately it is not convenient to gather water in a rainstorm when you need make-up water for your boiler. Most plants rely on water from rivers or lakes. Some rely on water from wells.
Great Lakes water is great because it is relatively pure in comparison to other water sources. "City Water" piped from the Great Lakes needs less treatment than river water or wells for small boiler rooms that run at pressures less than 300 psi.

Why is water from the Great Lakes relatively purer than river or well water? It started as ice when the Glaciers came south and carved out the Great Lakes. Freezing water separates water from solids. If you have ever seen a large block of ice used for ice sculpture, you will notice that it is completely clear except for a sliver of impurities in the center. Pure water freezes before dirty water.

Once water comes in contact with the Earth it starts dissolving what it comes in contact with. Water is known as the universal solvent. That means that given enough time, water can cut through just about anything it comes in contact with. Add CO2 from the air and it becomes a weak carbonic acid. Visit the Grand Canyon and you will see the result of water interaction with the Earth. Water in wells has had more time to dissolve minerals in the Earth that are harmful to boilers. That is why well water is the least desirable water to use for boiler make-up.

The two major minerals that cause problems with boilers are Calcium and Magnesium. Water dissolves these readily. Kentucky's Mammoth Cave, the largest cave in the world was created by water dissolving Limestone (Calcium Carbonate).

The major contaminants of boiler water are:

1. Calcium Carbonate, also known as Chalk, Calcite, Marble, Limestone, and Tums brand Antacid
2. Magnesium Carbonate, also known as Dolomite when Calcium is added
3. Calcium Sulfate, also known as Epsom Salts
4. Magnesium Sulfate also known as Gypsum (drywall) and Plaster of Paris

These 4 are the major culprits of Permanent Hardness that cause scale in a boiler. These are dissolved solids that cannot be filtered out by mechanical means. They have to be "undissolved" or returned back into their solids state by chemical treatment so they can be blown down from the boiler.

Calcium Bicarbonate and Magnesium Bicarbonate are referred as Temporary Hardness because they can be removed by boiling the feedwater in a Deaerating Heater before it reaches the boiler. Oxygen and Carbon Dioxide are also removed in the Deaerating Heater.

One of your jobs as a Boiler Operator is to treat the boiler with external pretreatment (before the water goes into the boiler) and with internal treatment (chemicals pumped into the boiler to stop the scale from baking out on boiler surfaces).

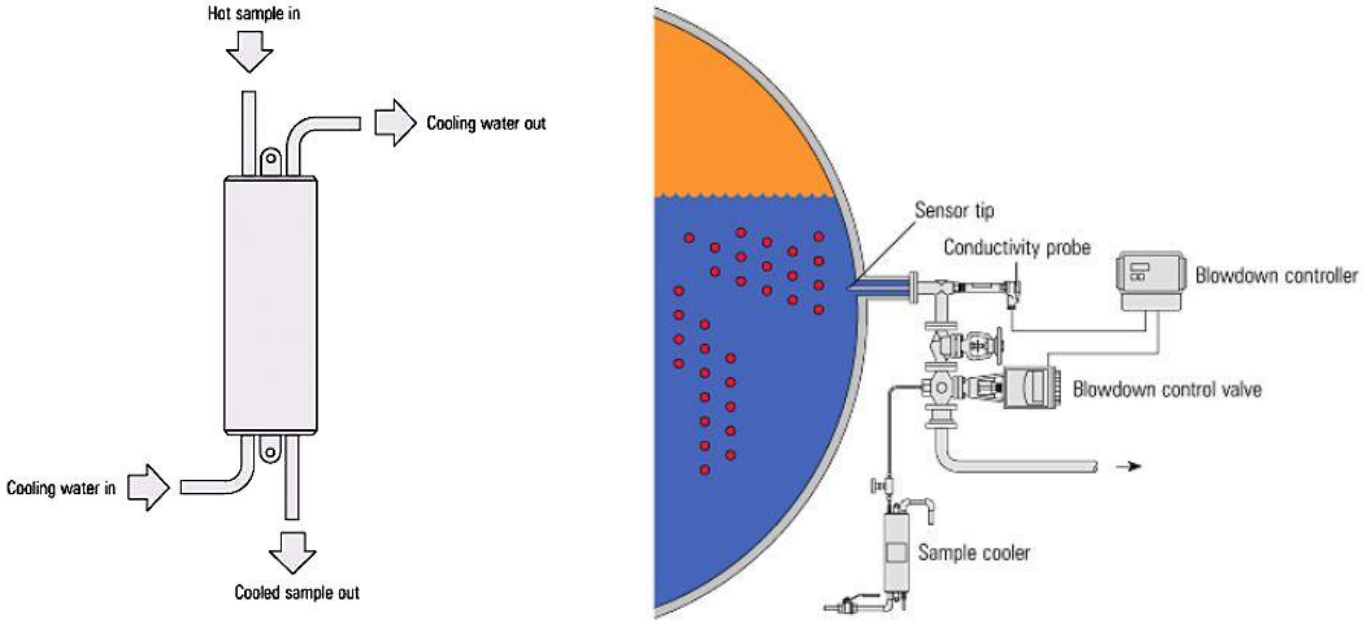
Pretreatment involves using Zeolite water softening or Hot Lime-Soda softening. Zeolite softening has taken over completely in smaller boiler plants. For pressures 300 psi and below it is the easiest way to produce feedwater with zero hardness.

Internal treatment involves using a variety of different types of chemicals. Using Phosphate is one of the most common. It turns the dissolved solids into a soft sludge that can be blown down from the boiler by the using the continuous blowdown and the bottom blowdown. The continuous blowdown controls Total Dissolved Solids. The bottom blowdown controls the removal of sludge. In order to know how dirty the boiler water is, how much blowdown is necessary, and how much of each chemical you have to add, you need to take boiler water tests every day. These tests are:

1. Conductivity or total dissolved solids (TDS)
2. pH
3. P Alkalinity
4. M Alkalinity
5. OH calculation
6. Chlorides
7. Sulfite
8. Phosphate
9. Softener Hardness
10. Condensate pH
11. Condensate TDS

GATHERING the BOILER SAMPLES

In order to do the tests you are going to have to collect good samples from the boiler, softener, and condensate line. The preferred sampling line spot is from a downcomer, but most plants use the continuous blowdown line. Make sure the continuous blowdown line has been running for at least 15 minutes before taking the sample. Modern Installations use a probe that can start and stop the continuous blowdown. Taking a sample from a stagnant line will give the wrong results. Experienced Boiler Operators can control the boiler chlorides within setpoint limits using the continuous blowdown line with just a hand metering valve like a needle valve or a globe valve. The water drains continuously down the pipe and the Operator adjusts the valve opening by hand. 24 hours later, the results are checked and adjusted again. The problem with the probes is that they can get dirty and unreliable. This will lead to overshooting the setpoint if the blowdown is closed for too long or draining expensive boiler chemicals if the valve fails open.



The boiler water sample should be cooled in a sampler that has a water cooling line. The water cooling line is a heat exchanger that has "City Water" in a coil that surrounds the boiler water sample line. The two waters do not meet or mix.

Flush the 200 ml sample bottle at least 3 times before taking the sample to ensure that the sample is not contaminated from the sample you took yesterday. All samples should be allowed to cool to 70 degrees before doing the test. That means your chemical testing area should be in a room that can be heated and cooled, not out in a boiler room without adequate provision for heating and cooling.

Mark the plastic sample bottles for each Boiler, Softener, and Condensate .

LAB SAFETY

All the chemicals you will be dealing with are hazardous. Get the Material Safety Data Sheet (MSDS) for each chemical so you know what you are dealing with. Another reason to have a separate room is so you can keep unauthorized personnel out and have adequate ventilation.
Wear safety glasses and a vinyl apron and nitrile gloves. Some of these chemicals will stain or eat holes in your clothes. Have a sink with hot and cold water and a chemical resistant countertop. Have an Emergency Shower and eyewash station in the room with a floor drain in case you get splashed with some chemical. A phone or Walkie Talkie to security should be in the room.
Have a First Aid Kit and a Fire Extinguisher in the room.
Do not eat or drink in the lab room.

Section 3 - Hazards Identification

Emergency Overview

Appearance: *Clear, colorless solution*

Danger! *Corrosive. Causes severe burns by all exposure routes. May be fatal if swallowed or inhaled.*

Target Organs: *Eyes, skin, respiratory tract, teeth.*

Potential Health Effects

Eye:

Causes severe eye burns. May cause permanent eye damage, including blindness and permanent corneal opacity.

Skin:

Causes severe skin burns.

TOTAL DISSOLVED SOLIDS OR TDS

The first test to be taken is the TDS (total dissolved solids) and pH. Using a combination pH and TDS meter you can do both at the same time. Rinse the meter cup with distilled water 3 times. Rinse the cup with the sample. Place the sample in the cup on the meter. The reading should be between 3000 and 3500 micromhos. Push the black button on the meter and take the reading of the conductivity in micromhos and write it down on the Water Test Log.

Push the red button to get the pH. Write it down on the log sheet.

Conductivity testing is used to monitor the amount of material dissolved in water by measuring its ability to conduct electricity. The more material dissolved in the water, the higher its conductivity will be.

TDS impurities concentrate in the boiler water, building up to produce scale just like in the tea kettle. If a boiler water's conductivity gets too high, indicating excessive dissolved material, steam will start to have trouble escaping the water's surface. As the dissolved solids become more concentrated, the steam bubbles formed are more stable, failing to pop when they reach the water surface in the boiler. This phenomenon is due to increased water surface tension from higher dissolved solids concentrations. The boiler at this point will begin to prime, or foam and bounce, resulting in tiny droplets of boiler water carrying over with the steam. Eventually, some of the steam space in the boiler fills with bubble foam which may get carried over into the main steam pipe. This is dangerous because now the steam is wet as it leaves the boiler, maybe causing water hammer. The TDS solids will contaminate control valves, heat exchangers, steam traps, and turbines.

While a Conductivity Meter and a TDS meter are not exactly the same, They both give an indication of how many impurities are in the boiler. You as a Boiler Operator use the conductivity results to adjust the continuous blowdown to keep the TDS within limits.

With everyday sampling, the cell cup may build up a residue or film on the cell walls that may cause the readings to become erratic. Use a 50/50 mixture of a common household cleaner (i.e. Lime-A-Way, CLR, etc) and deionized water. Pour into conductivity cell cup and scrub with a q-tip. Be sure to get around all the electrodes and the thermistor probe. On the DS handheld unit, use an acid brush to scrub the cell cup. Let it set for about 10 minutes. Rinse the cell cup thoroughly with tap water, then a final rinse with deionized water.

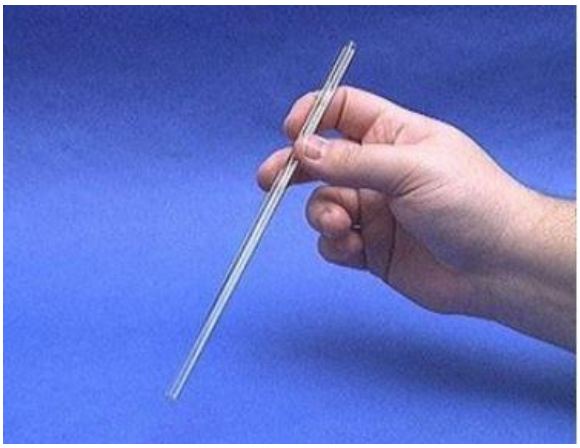
pH is a measure of the acidity or basicity (alkalinity) of water on a scale running from 0 to 14. The neutral point on this scale is pH 7; values below 7 indicate increasing acidity and those from 7 to 14 indicate increasing alkalinity. Each change in pH value by a whole unit indicates a 10 fold increase in acidity or alkalinity. For example, at pH 6 there is 10 times more acidity than at 7. pH 5 is 100 times more acid than pH 7. Similarly, pH 8 is 10 times more basic (alkaline) than pH 7 and pH 9 is 100 times more alkaline than pH 7, and so on.

pH can be measured either with an electric pH meter or colorimetrically using indicators that give different colors at different pH values.

Boiler pH should be kept between 10.5 and 11.5. Below 10.5, there is insufficient protection from corrosion and hardness compounds are not precipitated in the desired, free-flowing form. Above 11.5 there is the possibility of caustic embrittlement and carryover.

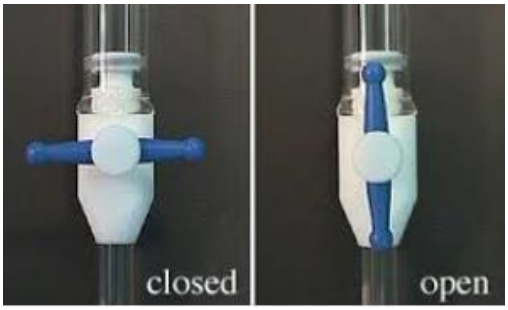
Condensate pH should be kept between 8.0 and 8.6. This pH is necessary to assure complete protection from carbonic acid corrosion.

The next test will be the P Alkalinity. The P stands for phenolphthalein (Fee Null Thay Lean), not pH. You will need a 200 ml casserole dish, a glass rod for stirring, and a 50 ml graduated cylinder. You will need a supply of N/50 sulfuric acid solution. N/50 is a very weak solution, about 1 gram of acid to 1 liter of water, and a small bottle of a chemical called phenolphthalein.



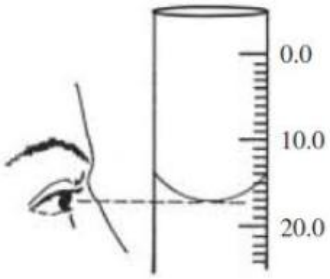
Rinse the casserole and the graduated cylinder with the boiler water sample. Measure 50 ml of the boiler water sample into the casserole. Add a few drops of Phenolphthalein into the boiler water and stir. It should turn pink. If it does not turn pink, make sure you have the right sample bottle. Place the casserole under the burette. You may have to adjust the clamp holding the burette.

There are several methods for measuring the N/50 sulfuric acid into the casserole dish. The best ways are either a squeeze bottle with a graduated 50 ml automatic zero burette or a glass bottle with a and a rubber bulb, again with a 50 ml automatic zero graduated burette. The first picture needs the double clamp stand in the picture next to it. If your boiler room does not have these, convince your company to buy them. You need accurate results for your tests and an eyedropper bottle is not accurate enough and does not hold enough solution for the best results.



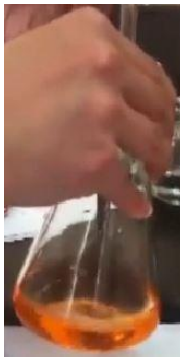
Squeeze the plastic bottle or rubber bulb to force the N/50 solution into the burette. The burette is open at the top, but the solution should automatically stop at the zero point and the excess will flow back into the solution bottle. As you stir the pink boiler water, start the flow from the burette into the casserole. The burette has a stopcock at the end to control flow. The burette glass is very brittle and breaks easily. Open the stopcock as shown in order to control the flow of the acid into the sample. Keep stirring with the glass rod as your other hand controls the stopcock. This requires a little practice. Slow down on the flow when the sample's pink color starts to lighten and close it completely when the sample turns clear.

They sell a shaker table that will mix the sample without having to stir it with a glass rod. Look straight across the burette at the meniscus and write down the acid used on the water treatment log. The meniscus is the lowest dip in the liquid level. This is the P reading.



The P reading tells you how alkaline your boiler water is. This test tells how much acid it took to neutralize the sample to a pH of 8.3.

"M" READING TEST
Add 4 drops of Methyl Orange indicator into the casserole into the now clear sample. The water will turn yellow. Continue stirring and adding N/50 sulfuric acid. Stop when the sample turns a salmon pink. This endpoint is harder to find than the M reading but with practice, it will become easy. The M reading turns salmon pink at pH 4.3.



After Methyl Orange After Titration

Multiply the P reading by 20 and you get the Calcium Carbonate in parts per million in the boiler. This is a standard reference point for expressing the acid neutralizing power of the boiler water. The alkalinity of boiler water should be high enough to protect boiler metal from acid attack, but low enough that it does not produce carryover from foaming. 300 parts per million is the minimum necessary in boiler plants under 300 psi. 700 ppm is a good top limit, with the P reading being 60 to 80 percent of the total alkalinity.

Multiply the M reading by 20 and you get a result known as total alkalinity

Alkalinity is typically measured as either P-Alkalinity (Phenolphthalein Alkalinity), M-Alkalinity (Methyl Orange Alkalinity), or OH-Alkalinity (Hydroxide Alkalinity).

P-Alkalinity is determined by a relatively simple titration procedure.

OH-Alkalinity is determined by calculation using P and M-Alkalinity (2xP-M=OH).

OH-Alkalinity is primarily the most important. If P-Alkalinity is in range, the OH-Alkalinity will be also. Boiler alkalinity is directly related to boiler pH so if the alkalinities are in range, the pH will be also.

The frequency of bottom blowdown will be determined by the test results. With Phosphate treatment, blow down at least once a day. Heavy solids that precipitate out have to be drained out the bottom blowdown valve Calcium Phosphate scale comes from lack of blowdown. Chelant and dispersant treatment do not require as frequent bottom blows but still bottom blow at least once a week. The proof of effective water treatment shows up at the yearly inspection. If you have been following the testing procedures and chemical additions religiously for the past year and your tubes are more scaled than last year, get rid of your chemical supplier and find a better one.

Chemicals are sold by the gallon. Boiler Chemicals weigh more than water. Water weighs 8.33 lbs a gallon. A Chemical treatment salesman that sells his chemicals for less but they weigh less is no bargain.

Larger Water Treatment Companies are reputable but the smaller companies need to be verified by contacting their other customers. Some unscrupulous companies will have you overfeed their chemicals and then blow it down to the sewer to increase their revenue.

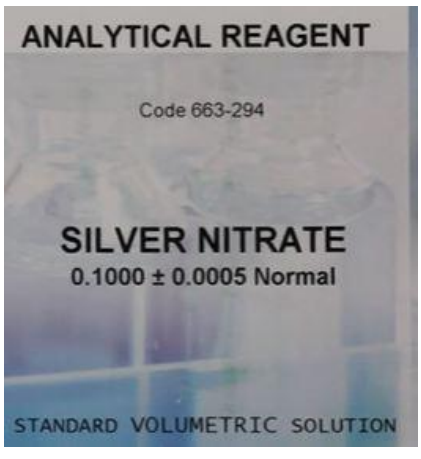
There are a lot of water treatment scams out there. Don't get stung by one.

CHLORIDE TEST

Chloride Tests are used to monitor cycles of concentration and to control blow down rates. Makeup water and boiler water should both be tested to determine the cycles of concentration. Makeup water quality can change with time. For example, failing water softener has the potential to increase the chloride concentration in the makeup water.

Take a 200 ml casserole that has been thoroughly cleaned. Rinse out the casserole with the boiler sample and add a 50 ml sample of boiler water into the casserole dish. Add drops of Phenolphthalein until the sample turns pink. Titrate with the N/50 sulfuric acid until the water turns clear. You are basically doing another P reading, but now you are going in a different direction.

Add 5 drops of Potassium chromate indicator to the casserole. The sample will turn yellow. You will have another large brown bottle that has silver nitrate in it. You will fill another 50 Ml burette with silver nitrate by squeezing the bottle. Silver Nitrate solution should not be exposed to strong light, hence the brown bottle. The dual clamp apparatus holds the silver nitrate burette. Place the casserole under the silver nitrate burette and titrate until the sample turns a brick red color. This is the endpoint. Multiply the result by 20 and you have the chlorides reading. The Chlorides reading is an indication of how dirty the boiler water. Increase the blowdown if the Chlorides reading is over 300 parts per million or the TDS is over 3500 micromhos for a boiler operating under 300 psi.



SULFITE TEST

Sulfite is an excellent oxygen scavenger that keeps oxygen from attacking boiler metal. By keeping an excess of sulfite in the boiler you know you have corrosion protection in the boiler.

In order to do a Sulfite Test you need to measure a 50 ml of sample of boiler water into the casserole.

Add 4 drops of Phenolphthalein Indicator. The sample will turn pink.

Add 1 plastic .7 cc dipperful of Sulfite Indicator at a time and stir between each additional dipperful until the pink color disappears. Add one more dipperful.

Slowly titrate the casserole with Potassium Iodide-Iodate solution while stirring constantly until a faint permanent blue color develops.

Multiply the burette reading by 10 to determine parts per million sulfite.
The control limits are between 30 – 60 ppm sulfite.
Theoretically, it takes about 8 ppm of sodium sulfite to react with 1 ppm of oxygen. To assure that this reaction goes to completion and that all oxygen is removed, an excess of 30 to 60 ppm of sulfite should be carried in the boiler water. Sulfite reacts with dissolved oxygen to form sodium sulfate, thus making the oxygen unavailable to damage system metals.

To eliminate oxygen corrosion and assure that the sulfite/oxygen reaction is complete before the feedwater reaches the boiler, sulfite should be fed as early as possible in the boiler cycle - preferably to the deaerator storage tank, feedwater storage tank or feedwater line - rather than directly to the boiler drum.

Normally the sulfite comes as a powder inside a thick clear plastic bag inside a cardboard drum. The cardboard drum has a metal band lock at the top. You measure cups of the sulfite powder into a bucket of hot water and stir to dissolve it. You then pour the bucket into a large stainless steel container with an agitator propeller on top. You fill the tank with hot water and start the agitator. A chemical pump on the bottom will pump the contents of the tank into the Deaerator over a 24 hour period. You recheck the reading and adjust your dosage to maintain the 30-60 ppm sulfite.

PHOSPHATE TEST

Phosphates are used in boilers to precipitate calcium hardness in a form which is readily removed by blowdown. This can be accomplished only if the phosphate levels are correct and alkalinity/pH levels are correct.

To assure that the calcium + phosphate reaction goes to completion, there must be at least 20 ppm excess phosphate in the boiler. If phosphate rises much over 60 ppm, it can contribute to boiler carryover. To a small extent, phosphate also helps prevent boiler corrosion by forming a protective iron phosphate coating on the boiler metal.

taylor
HIGH PHOSPHATE 5-100 ppm
Fold a filter paper circle into fourths.
Separate one layer from the other three to form a cone.
Insert the cone into a funnel.

1. Filter the boiler water to be tested with filter paper in a funnel to clarify and eliminate false high readings.

2. Fill two 5 mL test tubes to the 5 mL mark with filtered boiler water and place one each on either side of the comparator base as shown in the picture behind the slide, leaving the center hole open.

3. Rinse and fill the mixing test tube to 5 mL mark with filtered boiler sample.

4. Add Molybdate Reagent to second mark, 15 mL

5. Stopper and mix.

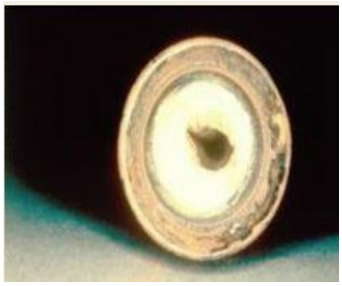
6. Add one brass dipperful of Stannous Reagent, put in the rubber stopper and mix well by turning tube up and down.

7. Wait one minute

8. Place mixing tube in the center hole of the viewing compartment between the two 5 mL test tubes. Compare the color in the center tube to the colors in the comparator by sliding the color samples back and forth while looking at the light until you get the closest match. Record the result on the Water Treatment Log.

9. You should keep the Boiler Water at 20 – 60 ppm phosphate. Too much will lead to scaling of the boiler.

10. Adjust the chemical feed pump feeding phosphate to the boiler to increase or decrease the phosphate to maintain the limits. A boiler with soft makeup from a Zeolite softener can be operated at higher cycles of concentration, thus requiring less blowdown and less chemical treatment in general.



Calcium Phosphate scale due to lack of blowdown

275 gallon Chemical Tote

SODIUM ZEOLITE SOFTENER HARDNESS TEST

Open the test tap from the softener and let it run to the drain for a minute. Rinse the casserole dish and the 50 ml thoroughly with softened water from the test tap of the softener. Fill the 50 ml cylinder and pour it in the casserole. Take the casserole back to the lab.

Add 1 ml Hardness Buffer and 1 brass measuring cup (0.14 gm) of Hardness Indicator Powder. If the water turns blue, no hardness is present, the hardness is reported as "zero," and the test is discontinued. If the water turns red, hardness is present and the test should be continued.

Titrate the red water with Standard Hardness Titrating Solution (1 ml = 1 mg $CaC0_3$) until the sample turns a sky blue. Record the results X 20 as Hardness. Zeolite softeners will always show a zero hardness unless there is something wrong with the softener or else the softener was not regenerated correctly. Check the brine tank for the salt level.

Zeolite resin exchanges non scale forming sodium ions for scale forming calcium and magnesium ions. To replenish the sodium ions used, units need to be regenerated with salt brine. This allows the resin to be reused many times.

Ion-exchange does not alter the water's pH or alkalinity. However, there is an increase in dissolved solids. Synthetic Zeolite, known as polystyrene resins, is most commonly used now. The cost is reasonable.

The ability of the resin to remove hardness from the water is related to the volume of resin in the tank. Softeners should remove about 50,000 grains of hardness per cubic foot of resin. Resins hold hardness ions until they are regenerated with a salt brine solution. The hardness ions are exchanged for sodium ions in the salt brine.

While the unit is in operation it is softening, usually controlled by a water meter. Once the water meter's preset amount of water has passed through the softener, it will switch over to the alternate unit that is in standby and beginning the regeneration cycle. There are four steps to the regeneration cycle

1. Backwash

2. Regeneration (brining)

3. Displacement (slow rinse)

4. Fast Rinse.

Backwash

During the service cycle, the downward flow of water causes suspended material to accumulate on the resin bed. Resin is an excellent filter and can trap particulate matter that has passed through upstream filtration equipment. The backwash step removes accumulated material and reclassifies the resin bed. In the backwash step, water flows from the underdrain distributor up through the resin bed and out the service distributor to waste. The upward flow lifts and expands the resin, allowing for removal of particulate material and resin fines and the classification of the resin. Resin classification brings the smaller beads to the top of the unit while the larger beads settle to the bottom. This enhances the distribution of the regenerant chemical and service water. Backwashing should continue for a minimum of 10 min or until effluent from the backwash outlet is clear. The backwash flow should be sufficient to expand the resin bed volume by 50% or more, depending on the available free-board (space above the resin bed). Insufficient backwash can lead to bed fouling and channeling. Excessive backwash flow rates result in the loss of resin. Backwash flow rates usually vary between 4-8 gallons per minute per square foot of bed area,

.**Regeneration (Brining**)

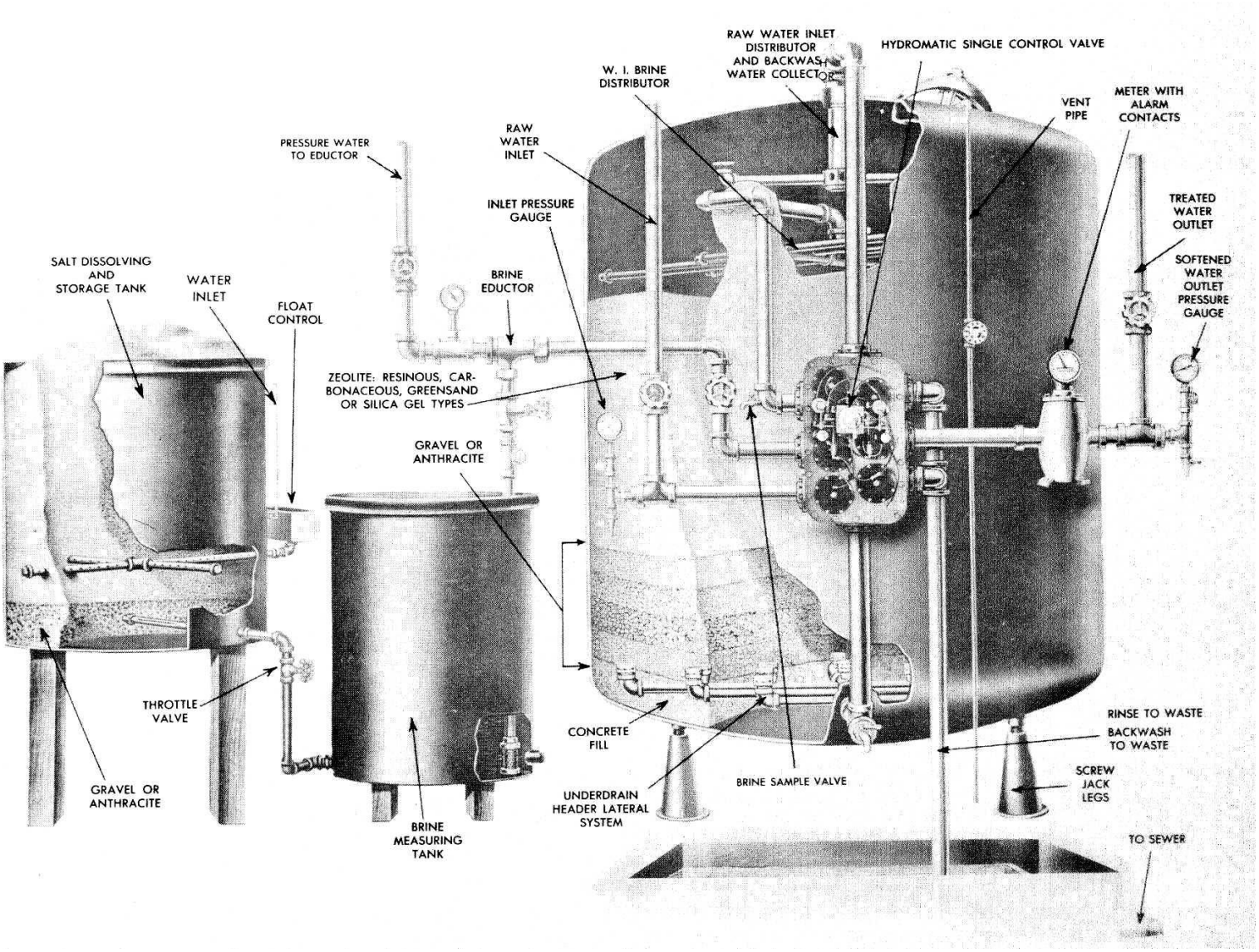
After backwash, regenerant brine is applied. The brine stream enters the unit through the regenerant distributor and flows down through the resin bed at a slow rate (usually between 0.5 and 1 gpm per square foot of resin). Brine flow is collected through the underdrain and sent to waste. The slow flow rate increases contact between the brine and resin. To achieve optimum efficiency from the brine, the solution strength should be 10% during brine introduction.

Displacement (Slow Rinse)

Following the introduction of regenerant brine, a slow flow of water continues through the regenerant distribution system. This water flow displaces the regenerant through the bed at the desired flow rate. The displacement step completes the regeneration of the resin by ensuring proper contact of the regenerant with the bottom of the resin bed. The flow rate for the displacement water is usually the same rate used for the dilution of the concentrated brine. The duration of the displacement step should be sufficient to allow for approximately one resin bed volume of water to pass through the unit. This provides a "plug" of displacement water which gradually moves the brine completely through the bed.

Fast Rinse

After completion of the displacement rinse, water is introduced through the inlet distributor at a high flow rate. This rinse water removes the remaining brine as well as any residual hardness from the resin bed. The fast rinse flow rate is normally between 1.5 and 2 gpm per square foot of resin. An effective fast rinse is important to ensure high effluent quality during the service run. If the softener has been in standby following a regeneration, a second fast rinse, known as a service rinse, can be used to remove any hardness that has entered the water during standby.



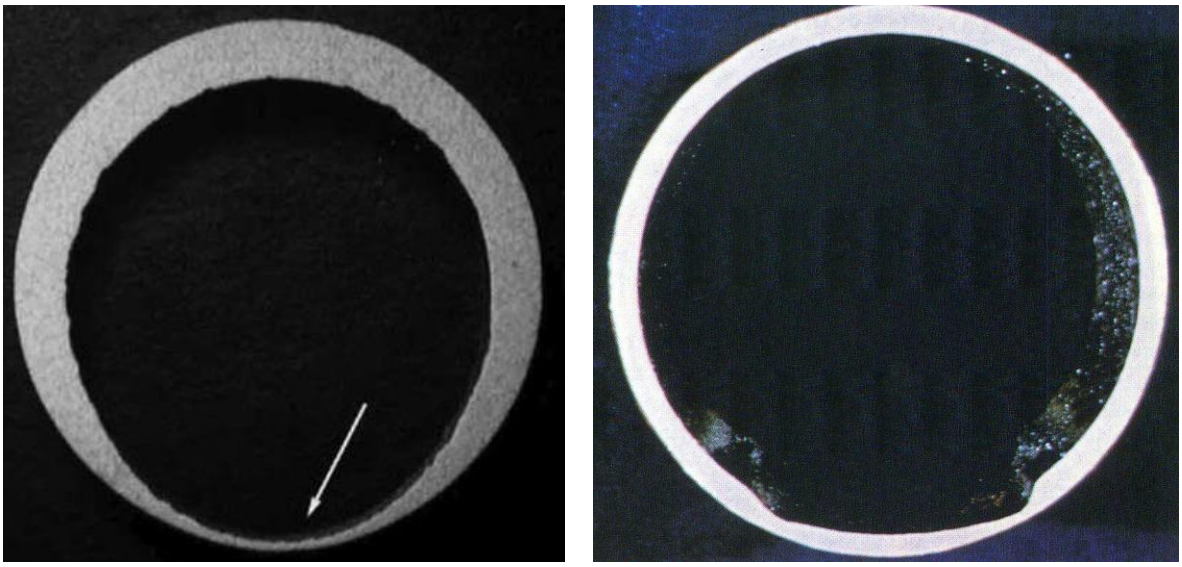
Zeolite Softener

CONDENSATE TESTS

The condensate sample is placed rinsed 3 times in the cup of the TDS pH meter and then Black button is pushed to find and write down the Conductivity in micromhos (or microsiemens which is the same thing). The red button is pushed and the pH is recorded on the Boiler water Test log sheet. The Conductivity should be 40 or less and the pH should be 8.5 to 9.5.

Amines

Return condensate is naturally corrosive because of its purity. The pH of pure water is easily decreased in the presence of carbon dioxide. Carbon dioxide dissolves in the water to form carbonic acid. Oxygen readily dissolves in pure water also. Both low pH and dissolved oxygen lead to corrosion in any water system especially in the presence of heat. Various amines are used to neutralize the resulting carbonic acid in condensate causing the pH to stabilize at higher less corrosive levels. The return condensate system is then protected from carbonic acid corrosion. Reducing corrosion decreases the amount of corrosion products that would normally return to boiler and form deposits. These deposits can be the most difficult to remove.



Thinning of condensate pipe due to Carbonic Acid Attack CO2

Oxygen Attack on Condensate Piping

An amine or blend of amines must be selected to meet the needs of each system. The choice of amines depends upon the length of the steam lines and their configurations. Amines are rated through distribution ratios. The higher the distribution ratio the further the amine travels. A high distribution ratio amine has a great affinity for being in the steam phase. A low distribution ratio amine has some affinity for staying behind in the water phase (in the boiler). The lower the distribution ratio the more it recycles in the system. Special amines known as filming amines are used to coat the inside of the return condensate system further protecting them from corrosion.

Neutralizing amines should be fed at a rate sufficient to produce a return condensate pH of 8 to 9 for best results. The exact feed rate depends on the percent of condensate return since higher return rates mean less makeup, the primary source of carbon dioxide. A higher return rate also means better recycling of the amine already fed into the system. As a result, less amine has to be fed to replace what is lost.

Amines may be fed in several locations depending on the configuration of the system. They may be fed directly into the boiler, the steam header, or into various strategic steam line locations. Some recycled amine will be lost in a Deaerating Heater since some steam is vented from the Deaerating Heater. Adding the amine to the steam header downstream of the steam line to the Deaerating Heater makes economical sense.

•When Oxygen enters the condensate return system, it will cause pitting on the top of the condensate return line.

•Oxygen can enter the system through vacuum breakers that are placed in the heating systems or on long runs to prevent water hammering.

•Oxygen can enter the system through open condensate receivers.

•Carbon Dioxide is formed in the boiler from the breakdown of carbonate (CO_3).

• CO_2 is a highly volatile gas; it leaves the boiler with the steam.

•The higher the raw water (make up) total alkalinity, the greater the amount of carbonate and hence, the higher the level of CO_2 in the steam.

•Carbonic acid is formed by bubbling carbon dioxide through hot water.

•As the steam is condensed in the trap, the carbon dioxide in the steam is bubbled through this hot condensate. The result is the formation of carbonic acid.

•The amount of total alkalinity in the raw water determines the amount of carbonic acid that is formed in the condensate system.

•Carbonic acid once formed, reduces the pH of the condensate.

•This acidic condensate then gradually eats away at the bottom of the condensate line, until the metal becomes thin enough for it to leak. This usually occurs first at the threaded section of the line.

•Besides destroying the condensate return piping, carbonic acid attack will bring iron back to the feed water system and to the boiler.

•This iron will cause increased corrosion, and can form hard to remove deposits in the boiler

Neutralizing Amines

•Neutralizing amines are used to control carbonic acid corrosion.

•The concept is that by using volatile alkaline amines, you neutralize the carbonic acid as it is formed. By maintaining a slightly alkaline pH in the condensate return system, you prevent carbonic acid attack.

•A pH between 7.6 - 8.8 is usually effective for the prevention of carbonic acid attack.

•Neutralizing amines can be fed to the boiler. This feed method will allow the majority of the amine will evolve out of the boiler with the steam.

• The most effective feed point is via a stainless steel injection quill directly into the steam header.

WHY Use A Filming Amine Instead Of Neutralizing Amines?

•Oxygen - Neutralizing amines have no effect on oxygen
•Economics - In highly alkaline water, the cost of using a neutralizing amine may be excessive. In this case, a cost comparison may show that it is much less expensive to use filming amines over neutralizing amines.

Filming Amines

•Filming amines are aliphatic hydrocarbon based materials that protect the condensate system by laying down a film on the metal surface.

•This film protects the metal from corrosion by preventing carbonic acid and oxygen from contacting the metal surfaces

Filming Amine Protecting the Condensate Pipe

Filming Amines - ODA

•Since ODA attaches to the metal surface, any corrosion byproducts that are present will be lifted off. Once lifted, these iron particles travel down line and can plug up strainers and lines.

Filming Amine completely clogged this condensate pipe

Corrosion Coupon

Testing Methods For Return Line Treatment

•Corrosion coupons and filter test are run to determine how effective the return line treatment program is. Coupons are inserted in the return condensate lines and removed and weighed for metal loss every 90 days.

Hardness Rating	Concentration of CaCo3 mg/l	Concentration of CaCO3 (grains/US Gallon)
Soft	0 to < 75	0 to < 5.2
Medium Hard	75 to 150	5.2 < 10.5
Hard	150 < 300	10.5 to < 21
Very Hard	300 and Greater	21 and Greater

Once you have logged the results of your boiler water tests, you make adjustments to the feed rates of the chemical pumps, and add sulfite to the chemical tank.

Drum Pressure PSIG	Max Boiler Water TDS
Up to 300	700 to 3500 ppm (mg/L)
from 300 to 450	600 to 3000 ppm (mg/L)
from 450 to 600	500 to 2500 ppm (mg/L)

Typical Boiler Chemical Test Log for a small to medium plant.

Building Name: _____ **Water System:** STEAM BOILER #

Location: _____

Month / Year: _____

	Boiler Water							Condensate		Softener	Chemicals Added			
Date	pH	TDS	SO_3	P	M	s	PO_4	pH	TDS	TH	PO_4	Caustic	SO_3	Amine
1														
2														
3														
4														
5														
6														
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Control Limits:

Parameter:	Boiler Water	Condensate	Softener
Total Hardness:	NA	2 ppm $CaCO_3$ maximum	2 ppm $CaCO_3$ maximum
pH:	10.5 - 11.5	8.5 - 9.5 (8.0 - 8.5 with humidification)	NA
TDS:	1500 - 3000 ppm (2000 - 4000 µS/cm)	40 ppm maximum (50 µS/cm maximum)	NA
Sulphite (SO_3):	30 - 60 ppm (50 - 100 ppm Na_2SO_3)	NA	NA
P Alkalinity:	NA	NA	NA
M Alkalinity:	700 ppm $CaCO_3$ maximum	NA	NA
OH Alkalinity:	150 - 300 ppm $CaCO_3$	NA	NA
Phosphate (PO_4):	40 - 80 ppm	NA	NA
Chlorides:			